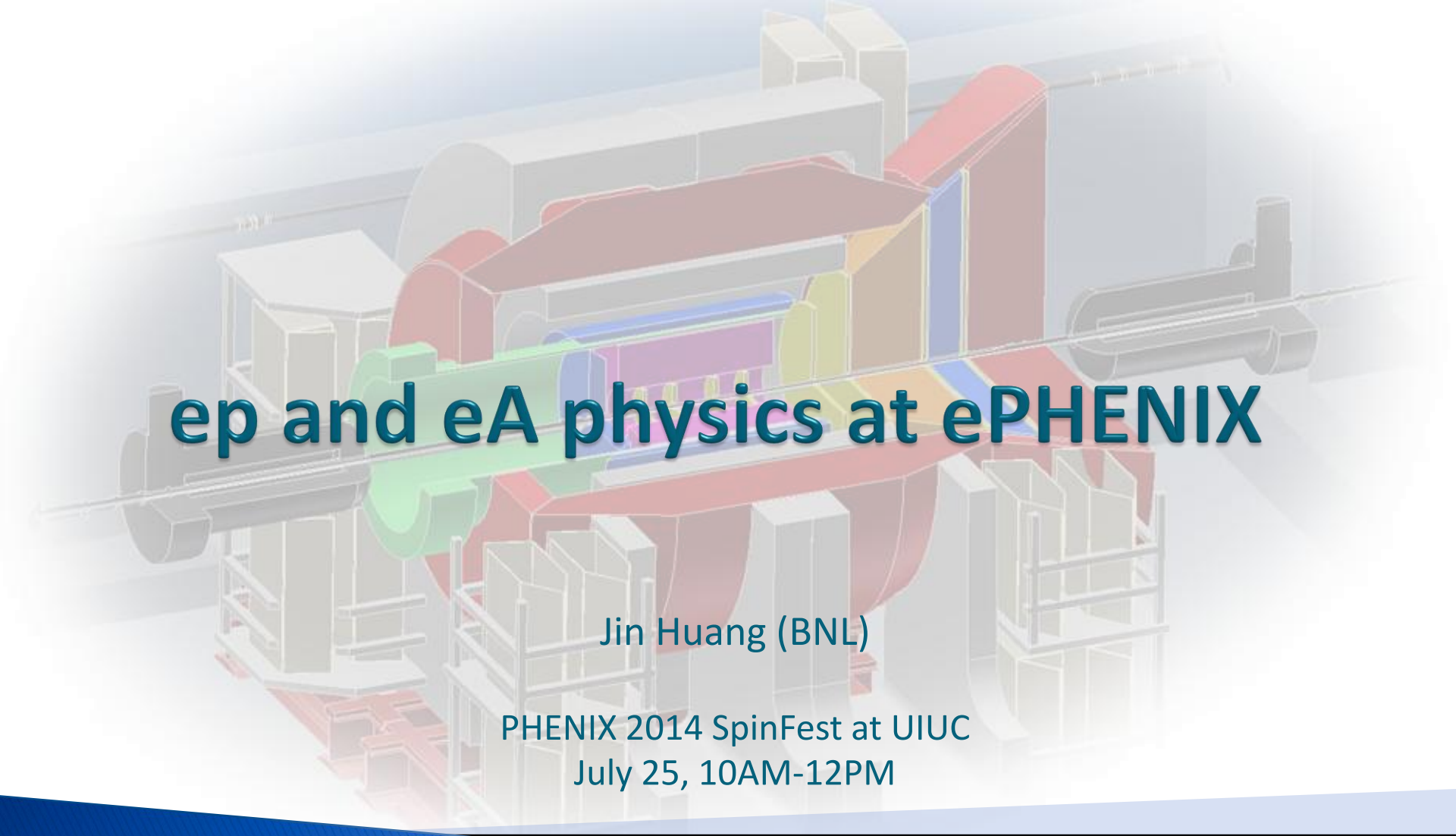


ep and eA physics at ePHENIX

Jin Huang (BNL)

PHENIX 2014 SpinFest at UIUC
July 25, 10AM-12PM

PHENIX

References:

- Highlights of physics program:
  - EIC-White Paper: "*Electron-Ion Collider: Next QCD Frontier*", arXiv:1212.1701 [nucl-ex]
  - INT-Write-Up: *Gluons and the quark sea at high energies: distributions, polarization, tomography*, arXiv:1108.1713 [nucl-th].
- Facility concepts:
  - eRHIC (BNL) concept: https://indico.bnl.gov/materialDisplay.py?materialId=0&confId=727
  - MEIC (JLab) concept: arXiv:1209.0757 [physics.acc-ph]
- Detector concepts:
  - ePHENIX Letter of intent: arXiv:1402.1209
  - eSTAR Letter of intent: https://drupal.star.bnl.gov/STAR/starnotes/public/sn0592
  - Also noted in facility concepts: eRHIC model detector and MEIC detector

Outline

Introduction
- Probing nucleons and nuclei
- DIS kinematics

e + p program at EIC
- Longitudinal spin structure
- Multi-dimensional structure

e + A program at EIC
- Probing saturation of gluons
- Energy loss of quarks

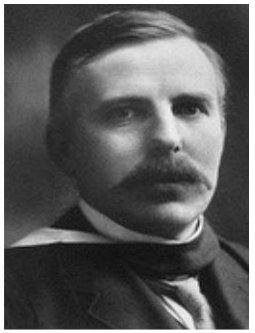
Major facility / experiment concepts
- eRHIC/mEIC/Existing experiment concepts

ePHENIX concept
- Detail on one of the most developed detector concept

Home work

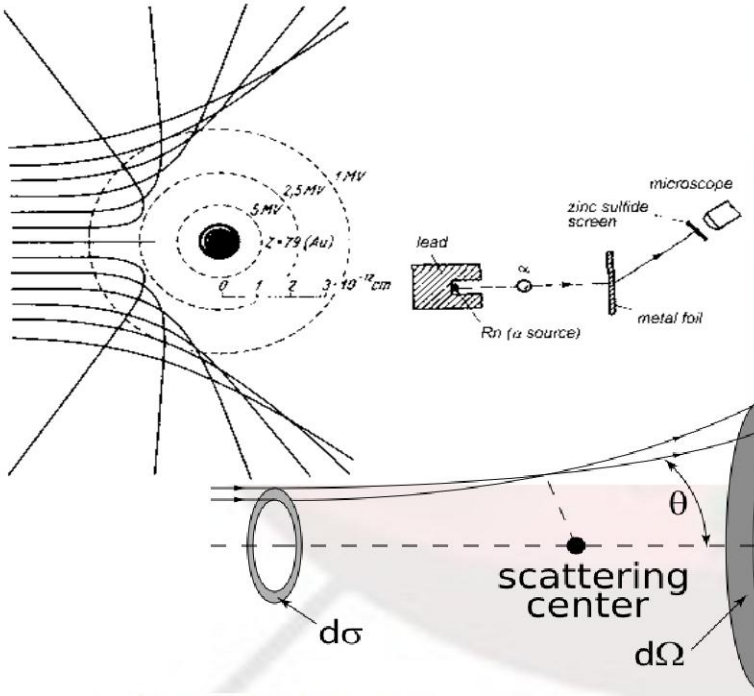
Exploring the nucleon: Of fundamental importance in science

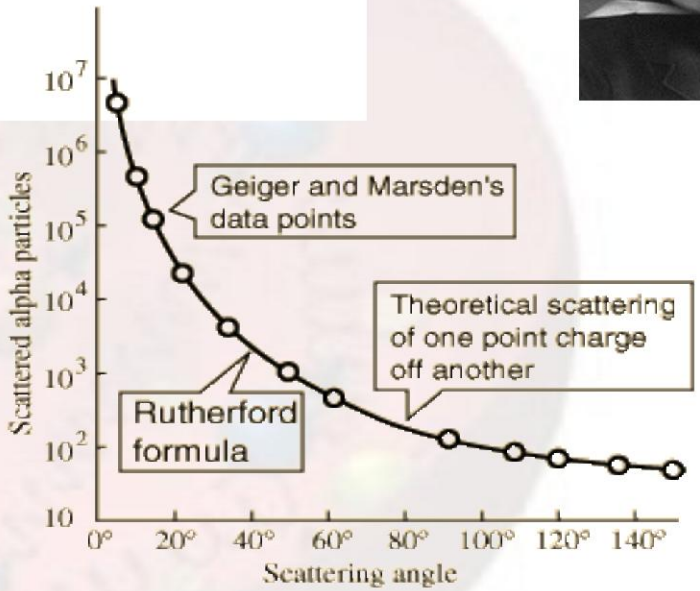
Rutherford Scattering



The Scattering of α and β Particles by Matter and the Structure of the Atom

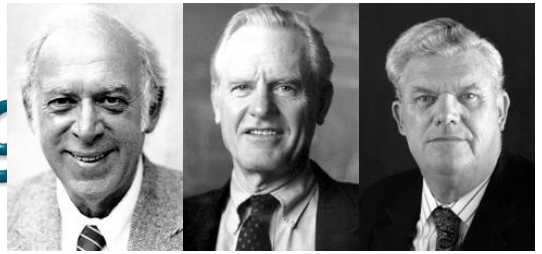
E. Rutherford, F.R.S.*
Philosophical Magazine
Series 6, vol. 21
May 1911, p. 669-688



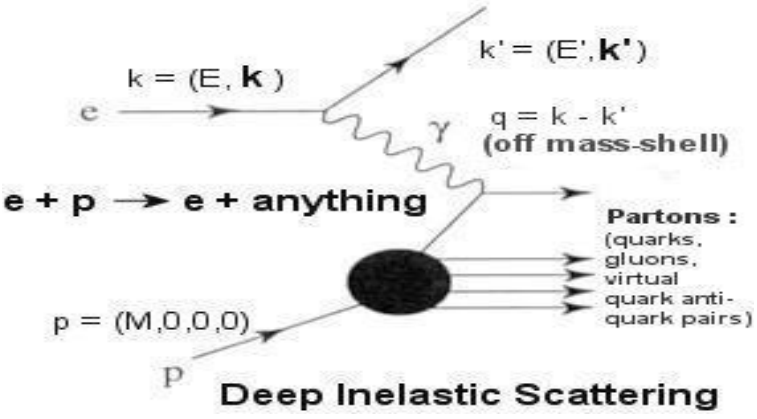


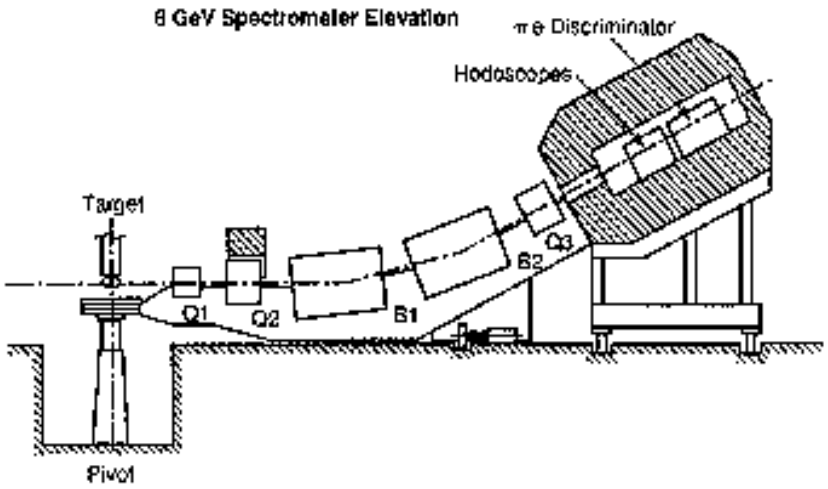
$$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha\hbar c}{2mv_0^2}\right)^2 \frac{1}{\sin^4(\theta/2)}$$

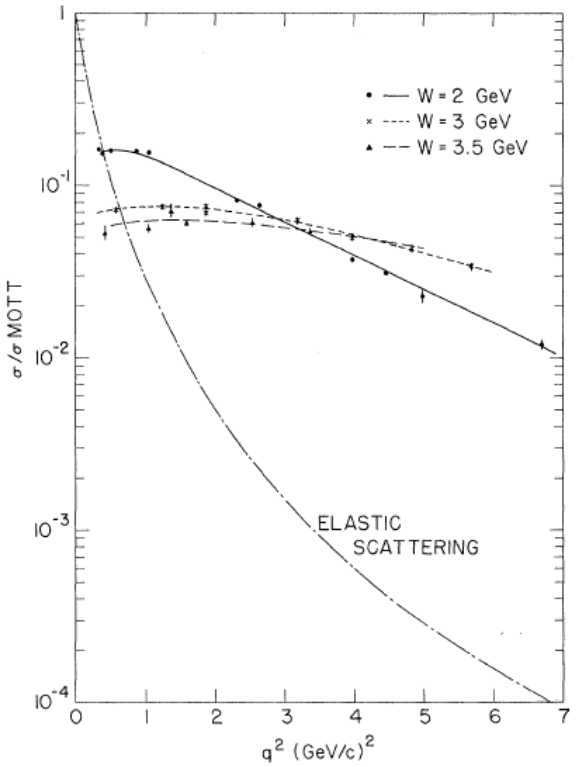
Deep Inelastic Scattering



Friedman Kendall Taylor





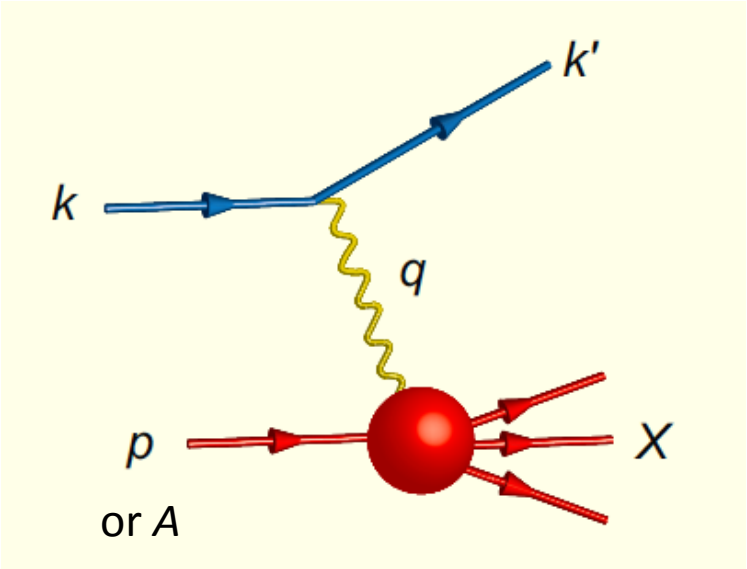


Bjorken Scaling: $Q^2 \rightarrow$ Infinity

Feynman Parton Model:

Point-like structure in Nucleon

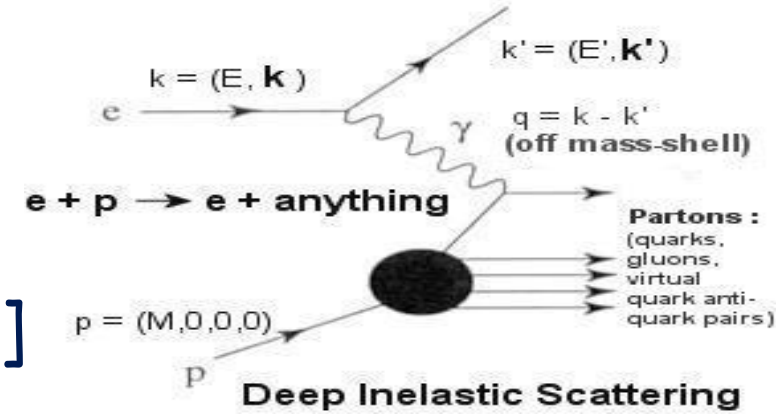
EIC basics - Deep scattering kinematics



- Inclusive DIS
  - Parton distributions
- Semi-inclusive DIS, measure additional hadron in final state
  - Kt-dependence
  - Quark energy loss in nuclear
- Exclusive Processes, measure recoiled nucleon
  - Nucleon tomography
  - Probe gluon densities
- Parity violating process to probe new physics beyond standard model

Luminosity requirement

DIS kinematics



- Kinematics [PDG Sec18.1]

$\nu = \dfrac{q \cdot P}{M} = E - E'$ is the lepton's energy loss in the nucleon rest frame (in earlier literature sometimes $\nu = q \cdot P$). Here, E and E' are the initial and final lepton energies in the nucleon rest frame.

$Q^2 = -q^2 = 2(EE' - \vec{k} \cdot \vec{k}') - m_\ell^2 - m_{\ell'}^2$ where $m_\ell (m_{\ell'})$ is the initial (final) lepton mass. If $EE' \sin^2(\theta/2) \gg m_\ell^2, m_{\ell'}^2$, then

$\approx 4EE' \sin^2(\theta/2)$, where θ is the lepton's scattering angle with respect to the lepton beam direction.

$x = \dfrac{Q^2}{2M\nu}$ where, in the parton model, x is the fraction of the nucleon's momentum carried by the struck quark.

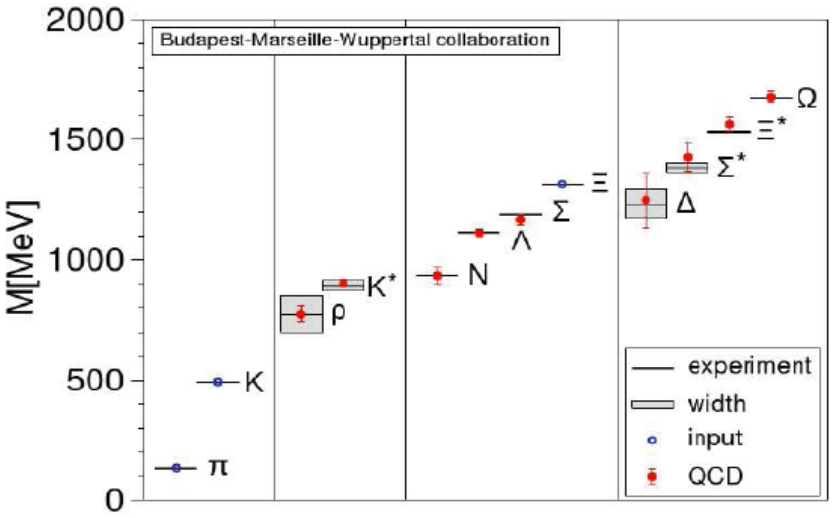
$y = \dfrac{q \cdot P}{k \cdot P} = \dfrac{\nu}{E}$ is the fraction of the lepton's energy lost in the nucleon rest frame.

$W^2 = (P+q)^2 = M^2 + 2M\nu - Q^2$ is the mass squared of the system X recoiling against the scattered lepton.

$s = (k+P)^2 = \dfrac{Q^2}{xy} + M^2 + m_\ell^2$ is the center-of-mass energy squared of the lepton-nucleon system.

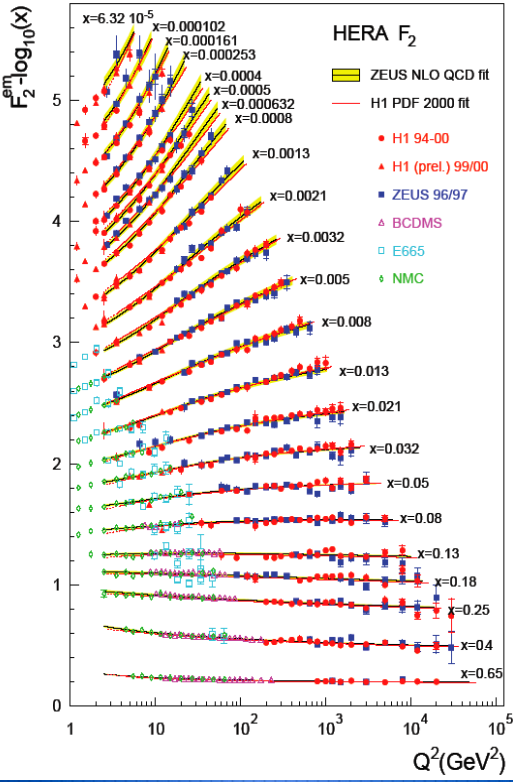
Successes of QCD

- **At low Energy:** Hadron Mass Spectrum from Lattice

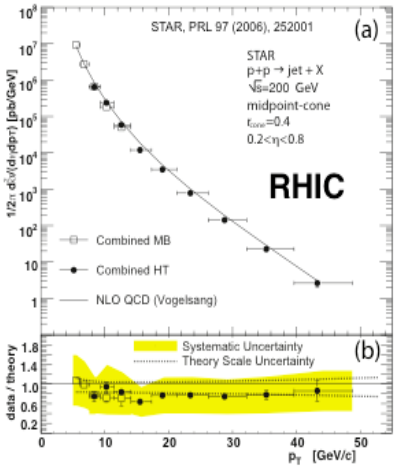


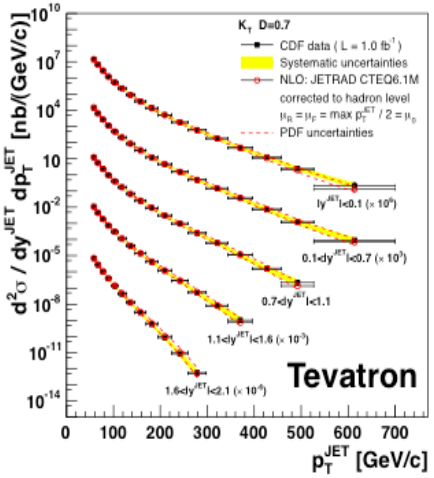
- **At high Energy:** Asymptotic freedom + perturbative QCD

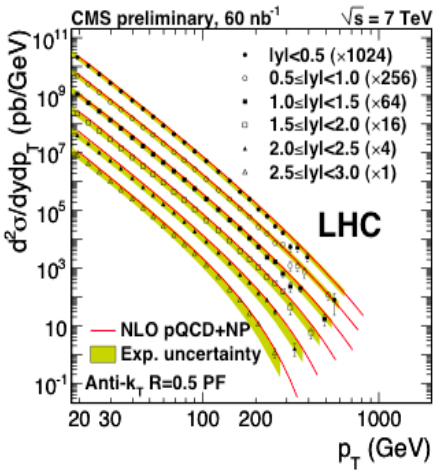
Measure e-p at 0.3 TeV (Hera)



Predict p-p and p-pbar at 0.2, 1.96 and 7 TeV

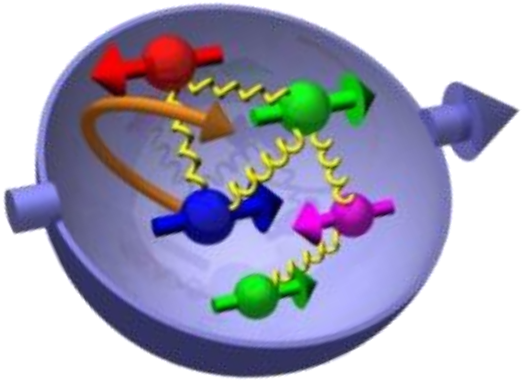


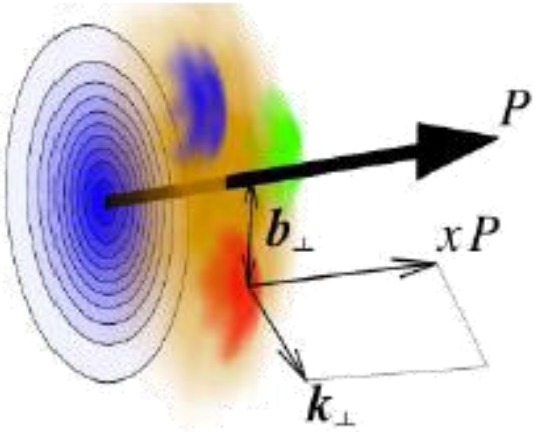




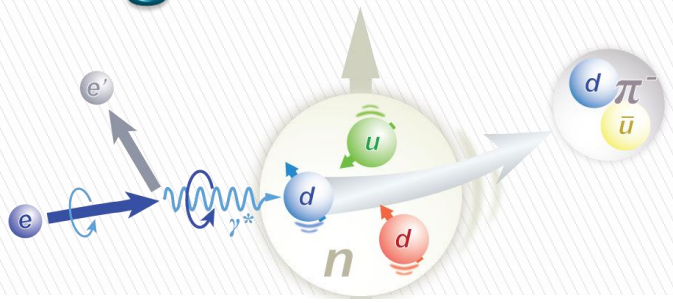
EIC Physics goals 1: nucleon as a laboratory for QCD

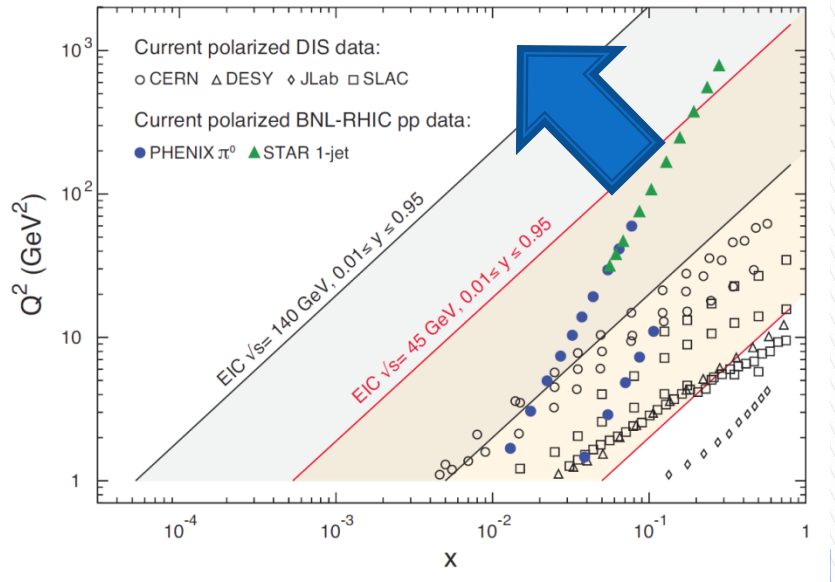
- The compelling question:
  How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- Deliverable measurement using polarized electron-proton collisions
  - The longitudinal spin of the proton, through Deep-Inelastic Scattering (DIS)
  - Transverse motion of quarks and gluons in the proton, through Semi-Inclusive Deep-Inelastic Scattering (SIDIS)
  - Tomographic imaging of the proton, through Deeply Virtual Compton Scattering (DVCS)
- Leading detector requirement:
  - Good detection of DIS electrons
  - Momentum measurement and PID of hadrons
  - Detection of exclusive production of photon/vector mesons and scattered proton

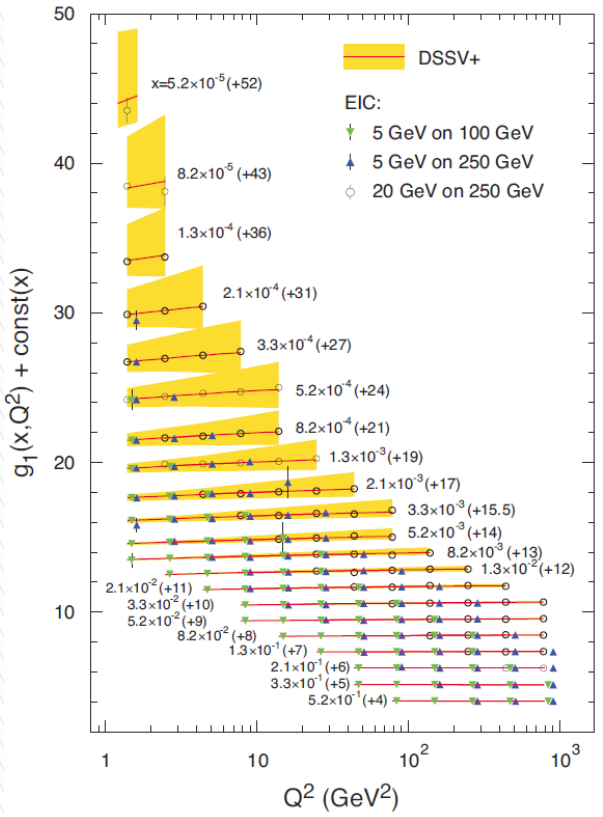




The longitudinal spin of the proton, through DIS



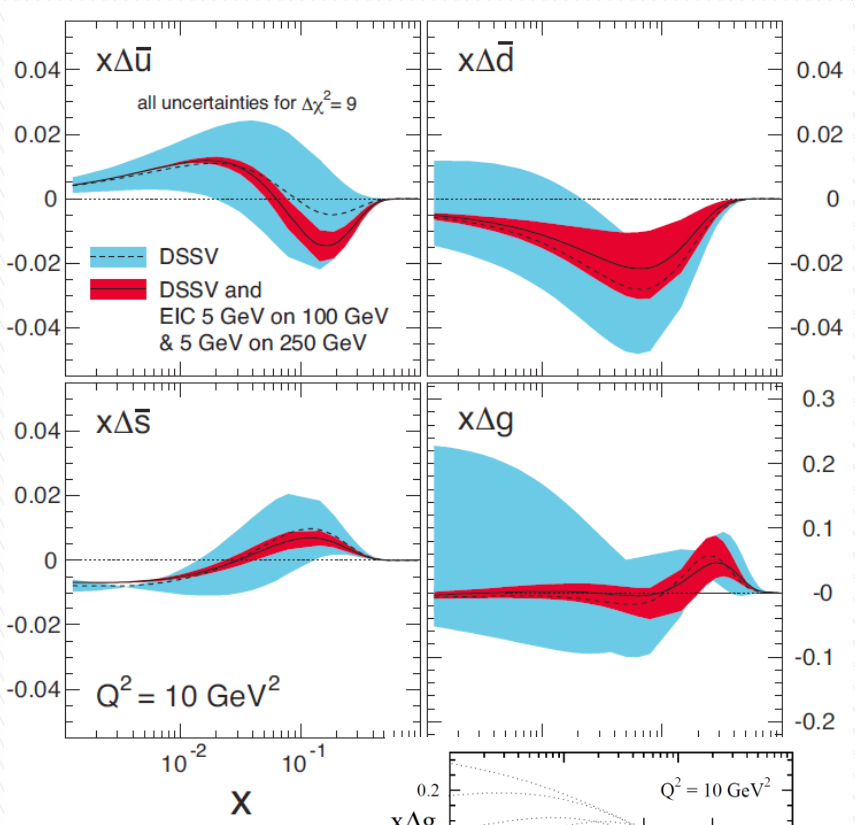


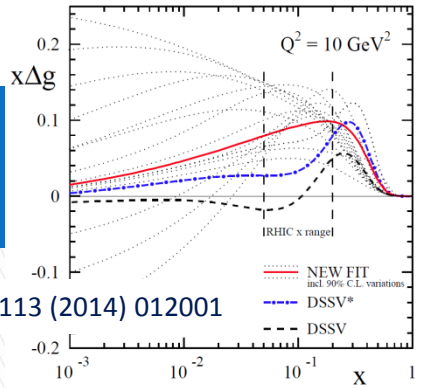


Expanding in kinematics reach

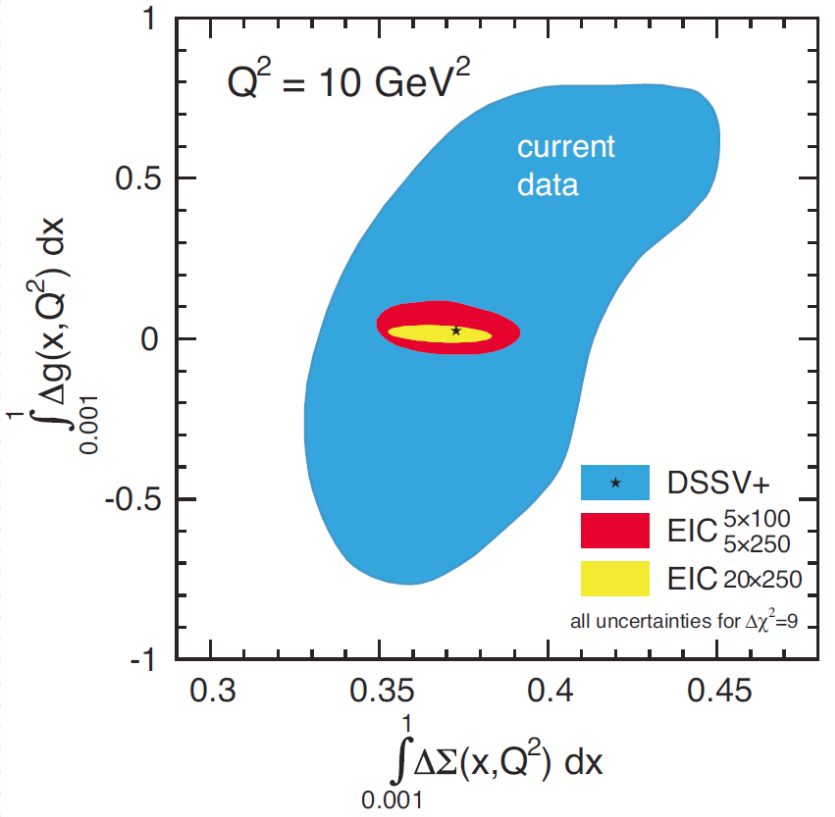
as well as in precision

Significant advance in spin structure





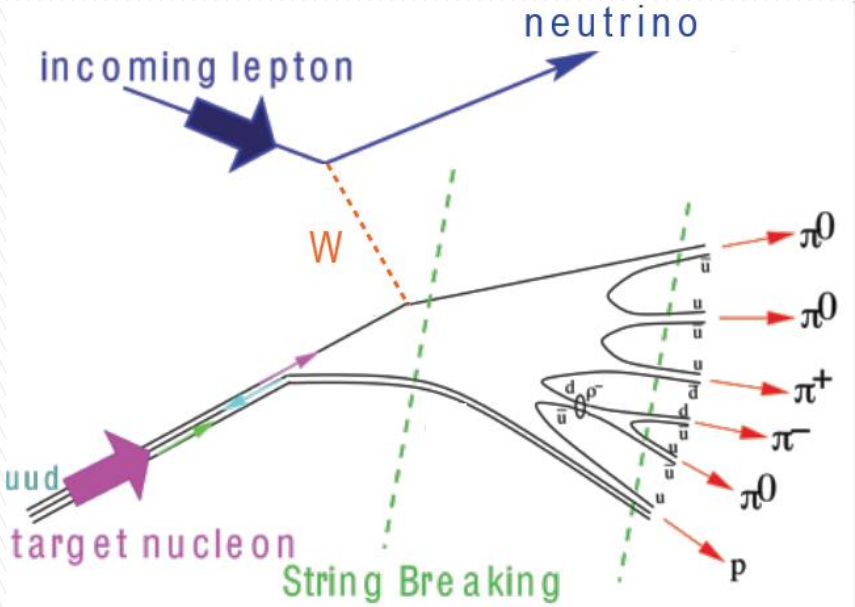
x-dependent



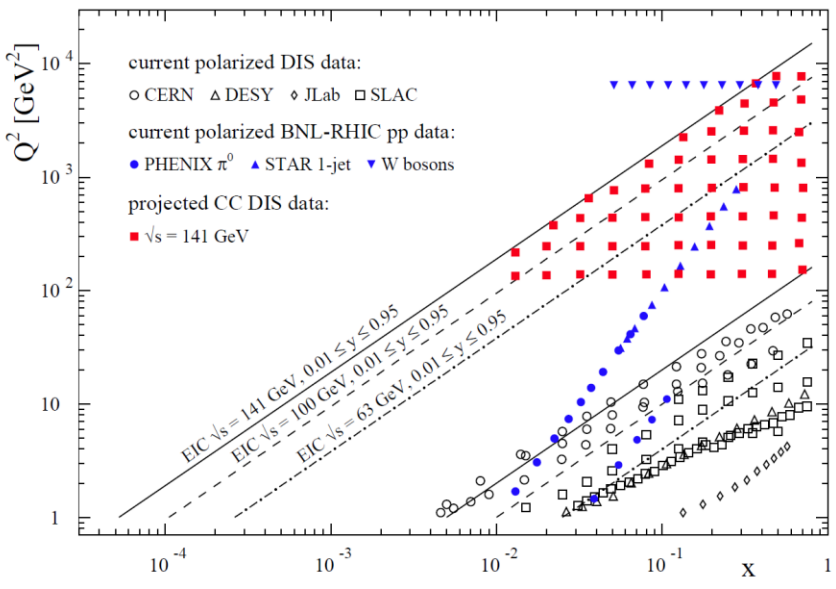
Quark – gluon spin decomposition

Phys.Rev.Lett. 113 (2014) 012001

Also charge current exchange



Courtesy: Thomas Burton



Phys.Rev. D88 (2013) 114025

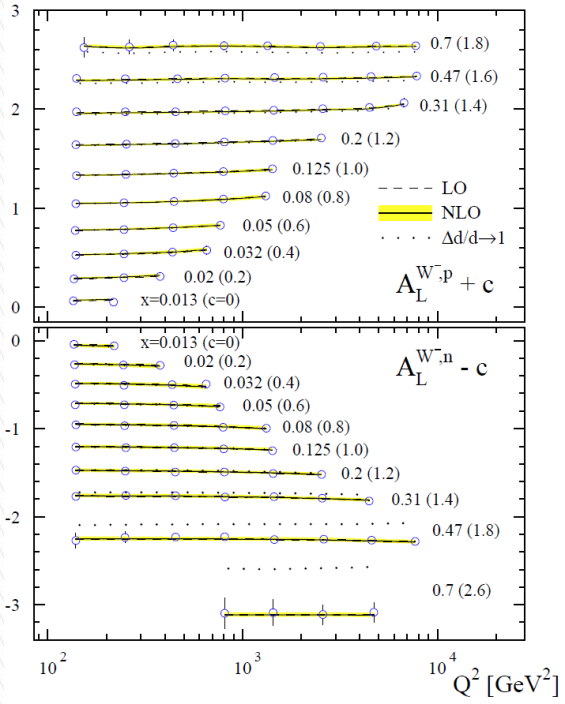
CC and final states

Effective kinematic bins

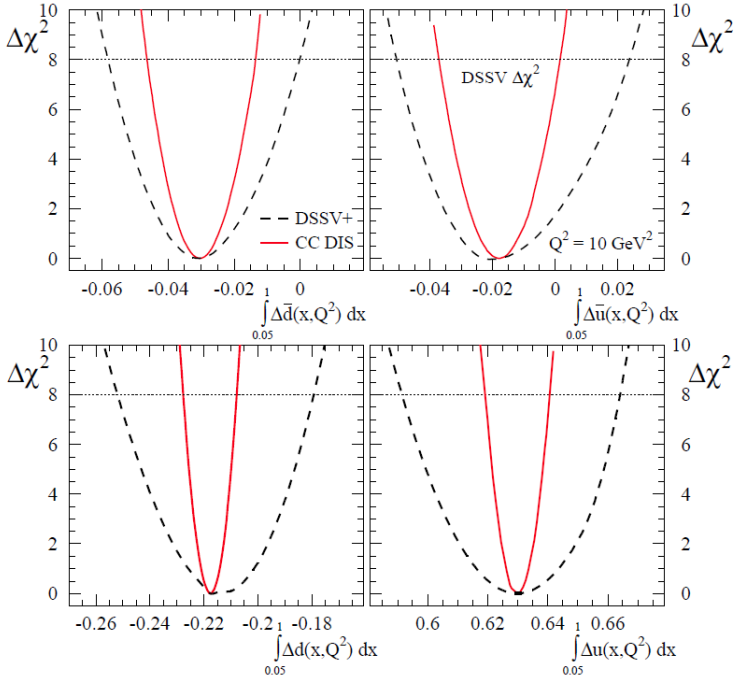
Charge current exchange - projections

Phys.Rev. D88 (2013) 114025

- Check high-x polarized PDF w/o using fragmentation function and at large scale
- With prospect of probing s quark PDF using s->W->c final states



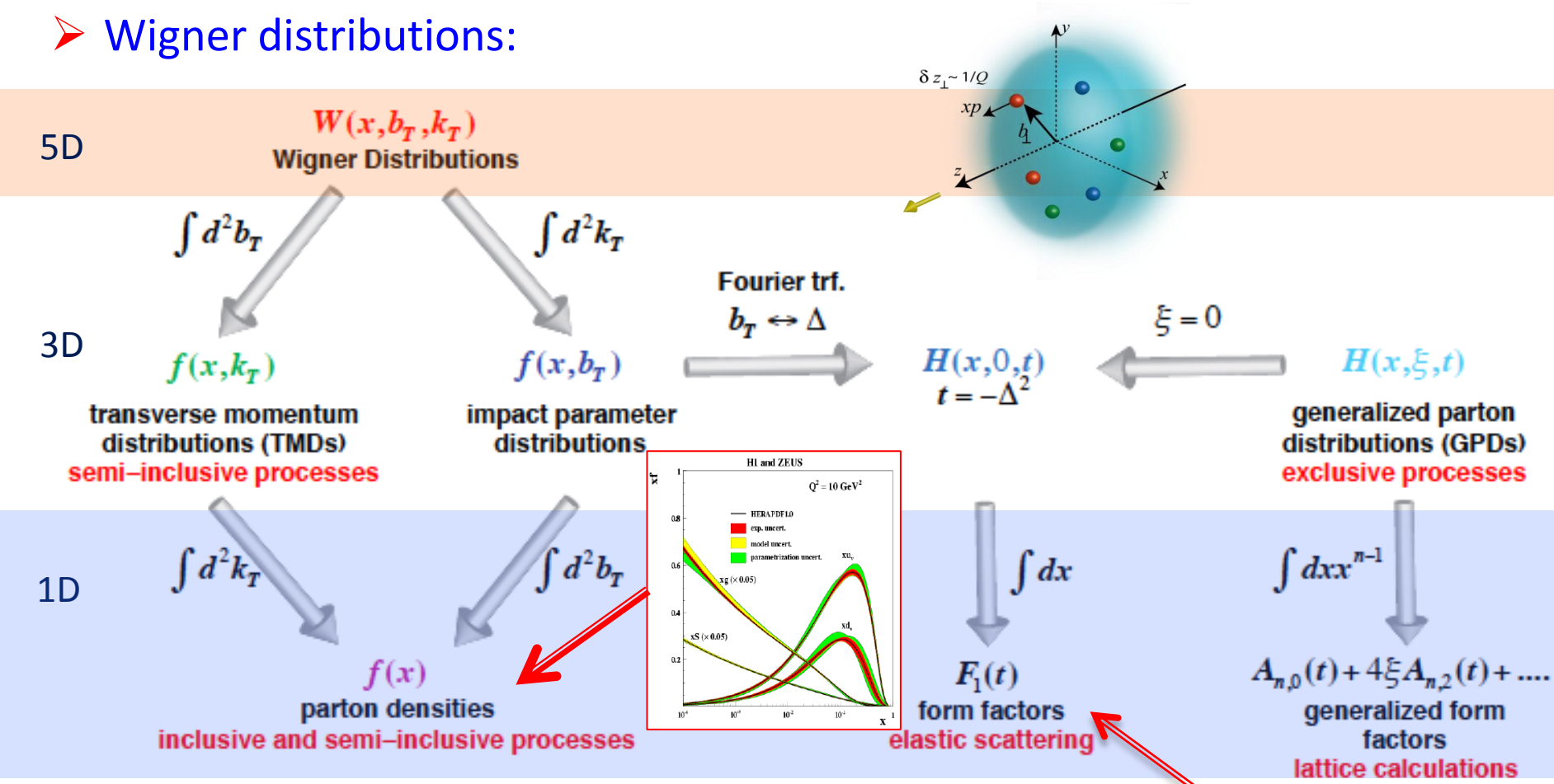
Asymmetry projections



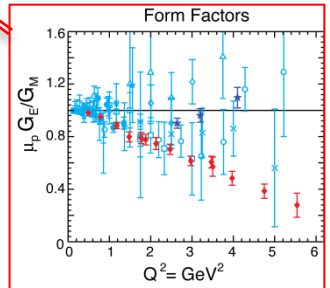
PDF integrals (cmp. DSSV)

Multi-dimensional view of nucleon

- Wigner distributions:



- EIC – 3D imaging of sea and gluons:



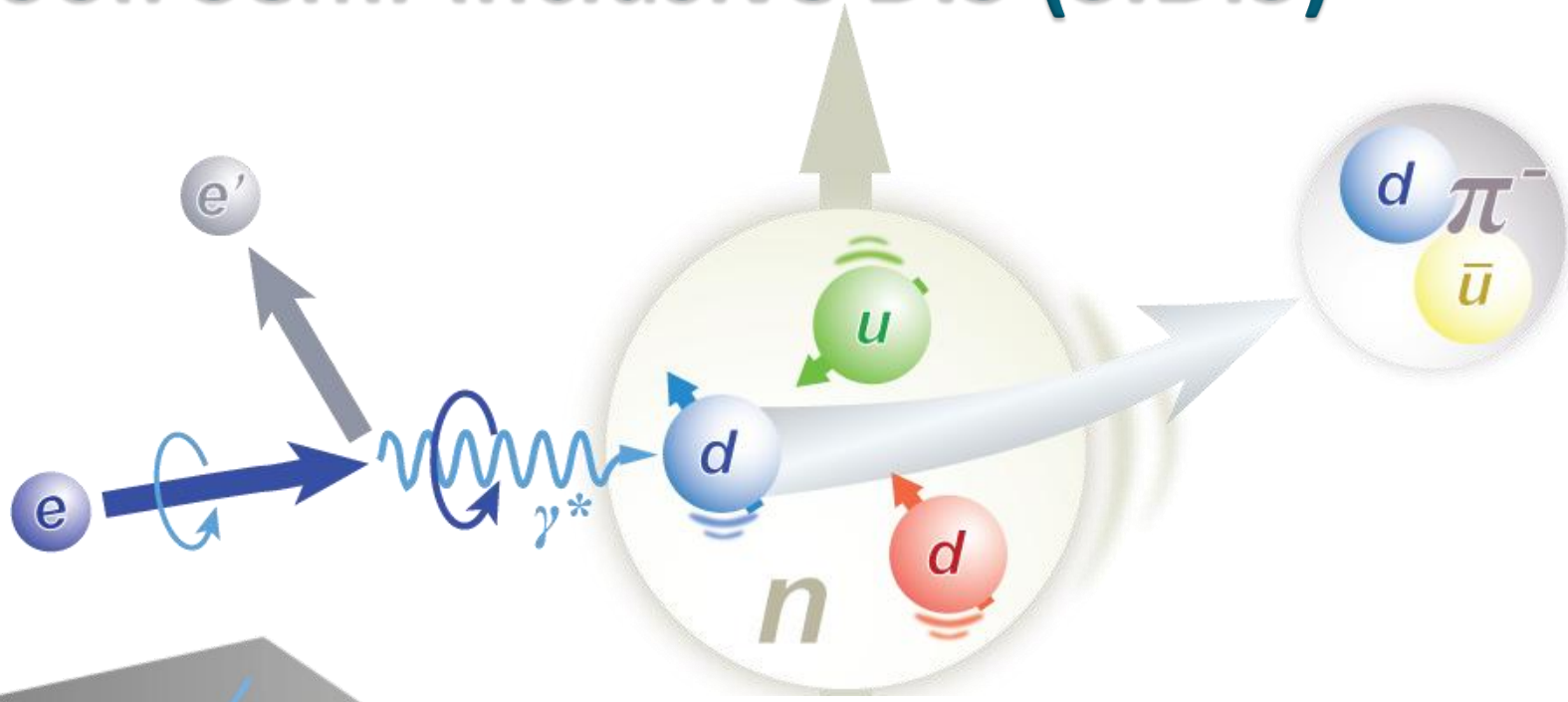
- **TMDs – confined motion in a nucleon (semi-inclusive DIS)**
- **GPDs – Spatial imaging of quarks and gluons (exclusive DIS)**

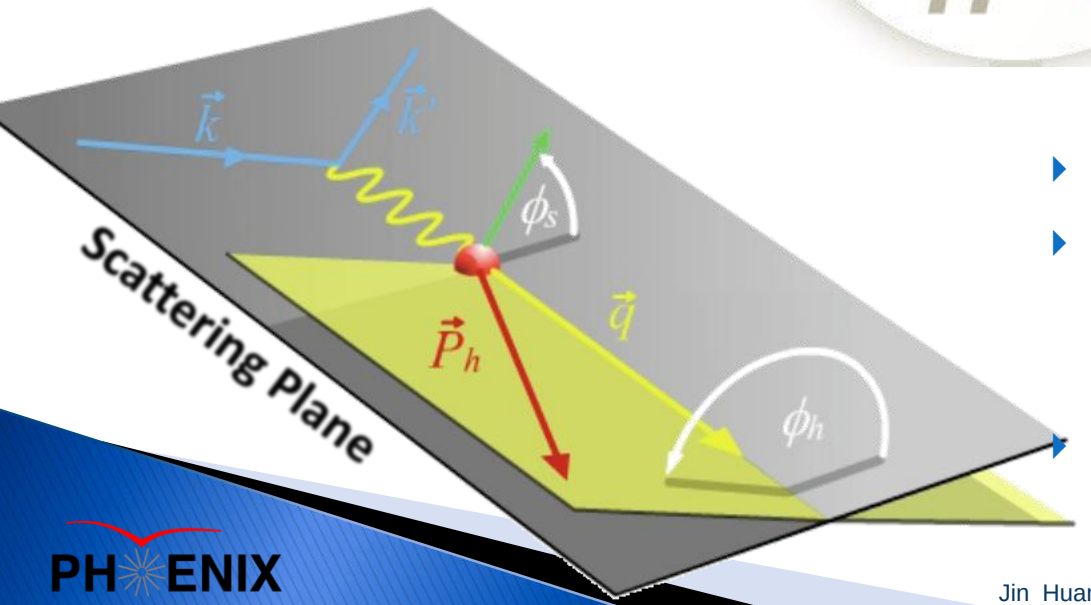
Leading-Twist TMD PDFs

Nucleon Polarization	Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = − Boer-Mulders
L		g_1 = − Helicity	$h_{1L}^\perp$ = − Worm Gear (Kotzinian-Mulders)
T	$f_{1T}^\perp$ = − Sivers	g_{1T} = − Worm Gear (trans-helicity)	h_1 = − Transversity $h_{1T}^\perp$ = − Pretzelosity

: Survive trans. momentum integration

Tool: Semi-inclusive DIS (SIDIS)





- Gold mine for TMDs
- Access all eight leading-twist TMDs through spin-comb. & azimuthal-modulations
- Tagging quark flavor/kinematics

TMDs in SIDIS Cross Section

$$\frac{d\sigma}{dxdyd\phi_S dzd\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\cdot$$

$$\{F_{UU,T} +$$

$$+\varepsilon\cos(2\phi_h)\cdot F_{UU}^{\cos(2\phi_h)} + \ldots$$

$$+S_T\lambda_e[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\cdot F_{LT}^{\cos(\phi_h-\phi_S)} + \ldots]$$

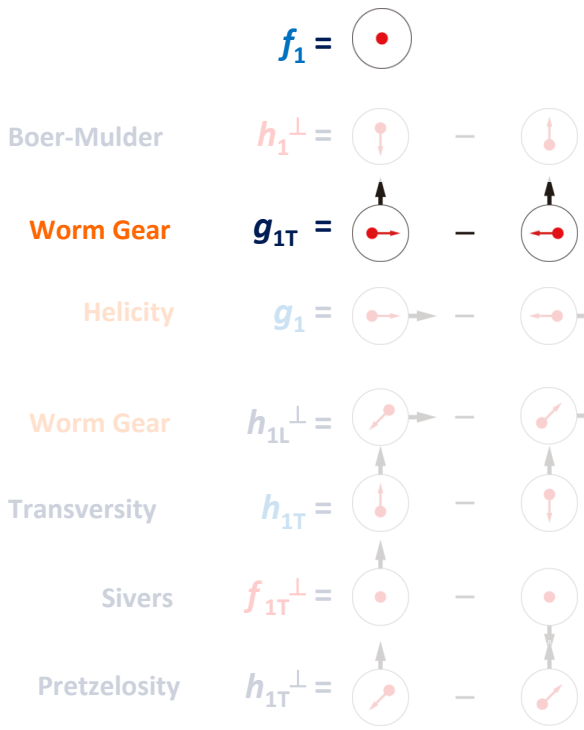
$$+S_L\lambda_e[\sqrt{1-\varepsilon^2}\cdot F_{LL} + \ldots]$$

$$+S_L[\varepsilon\sin(2\phi_h)\cdot F_{UL}^{\sin(2\phi_h)} + \ldots]$$

$$+S_T[\varepsilon\sin(\phi_h+\phi_S)\cdot F_{UT}^{\sin(\phi_h+\phi_S)}$$

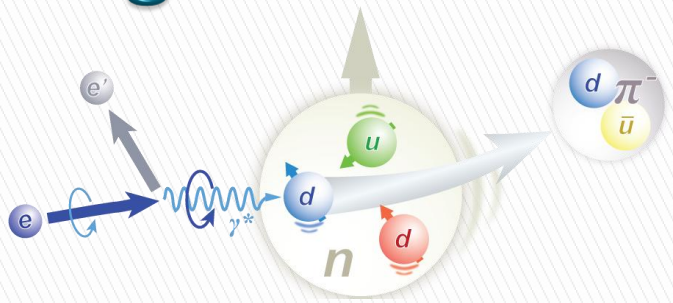
$$+\sin(\phi_h-\phi_S)\cdot(F_{UT}^{\sin(\phi_h-\phi_S)} + \ldots)$$

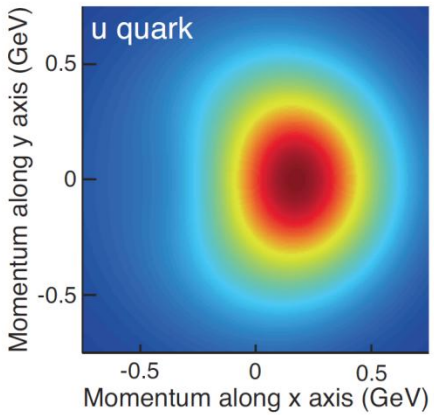
$$+\varepsilon\sin(3\phi_h-\phi_S)\cdot F_{UT}^{\sin(3\phi_h-\phi_S)} + \ldots]\}$$

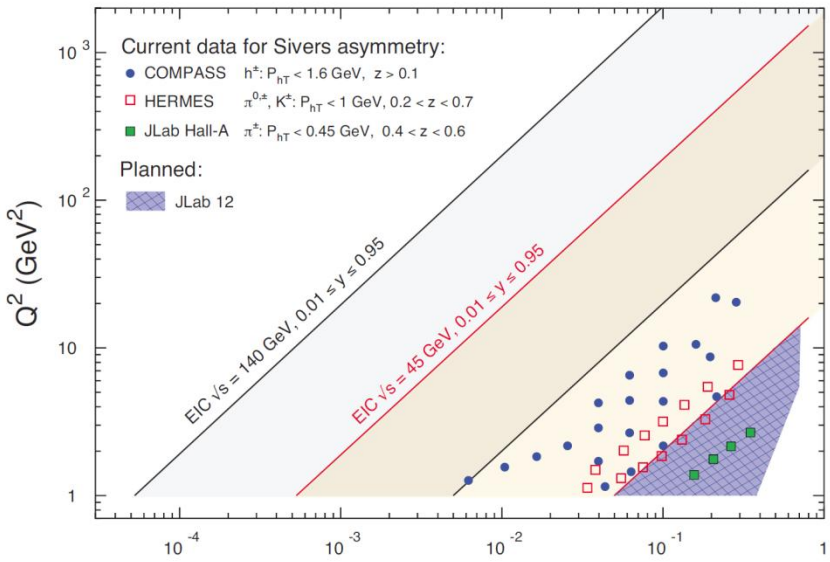


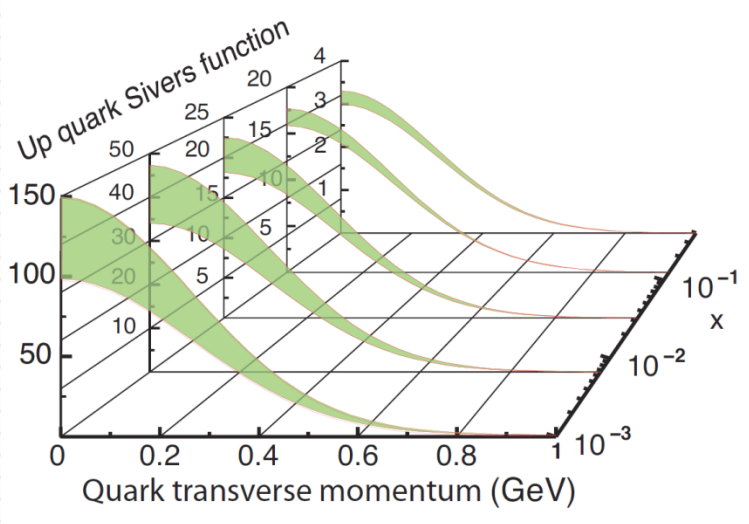
S_L, S_T: Target Polarization; λ_e: Beam Polarization

The longitudinal spin of the proton, through DIS







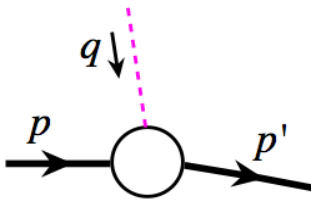


Dramatic expands kinematics reach

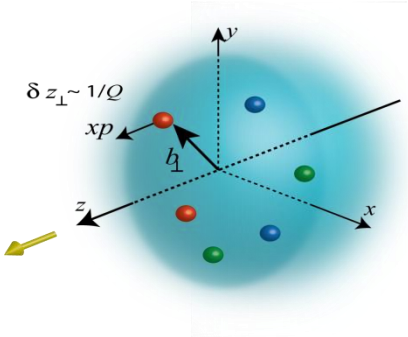
as well as in precision

Spatial imaging of quarks and gluons

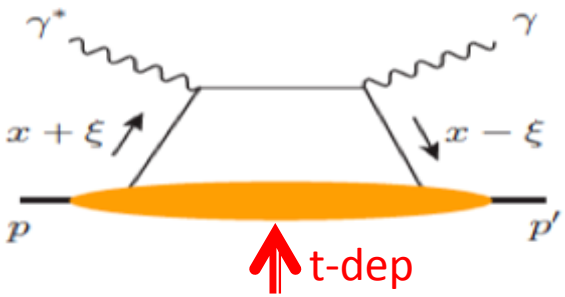
- **Need Form Factor of density operator:**



- ✧ Exchange of a colorless "object"
- ✧ "Localized" probe
- ✧ Control of exchanged momentum



- **Exclusive processes - DVCS:**



$$\frac{d\sigma}{dx_B dQ^2 dt}$$

$$t = (p' - p)^2$$

$$\xi = (P' - P) \cdot n/2$$

GPDs

$$H_q(x,\xi,t,Q), E_q(x,\xi,t,Q), \ldots$$

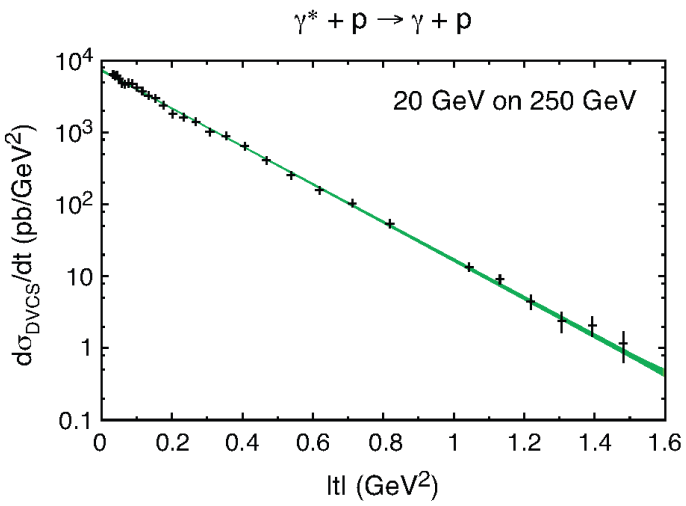
F.T. of t-dep

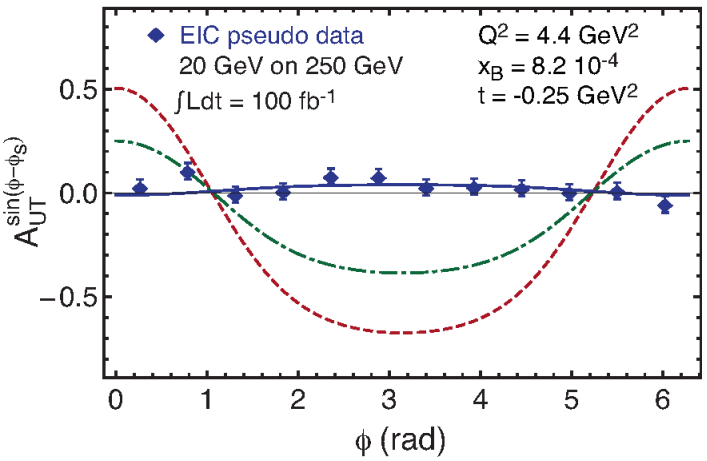
Spatial distributions

JLab 12: Valence quarks

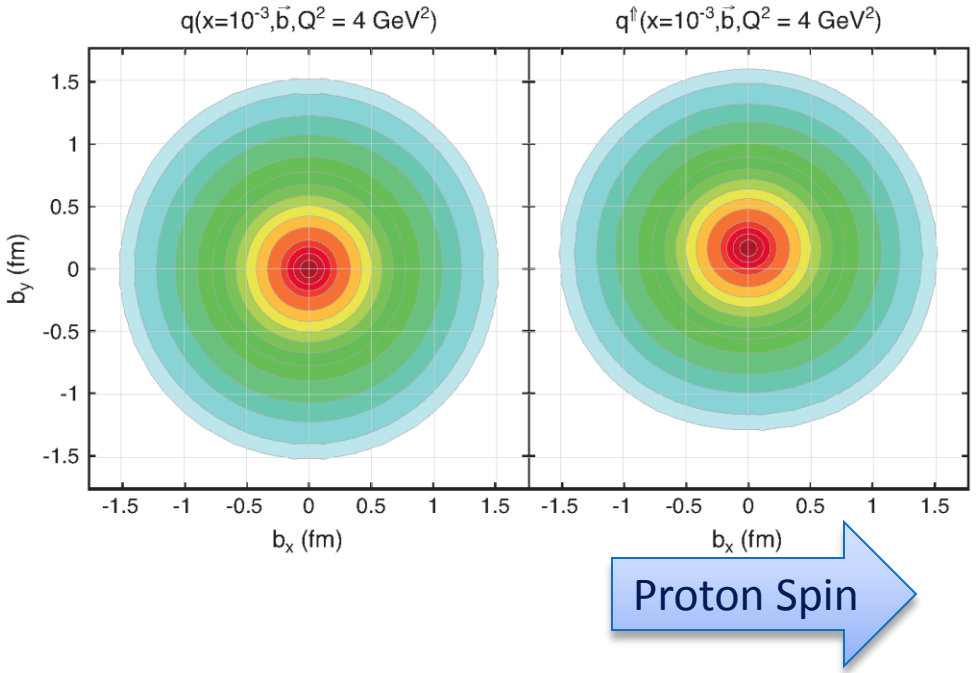
EIC: Sea quarks

Spatial imaging of sea quarks





EIC: Sea quarks

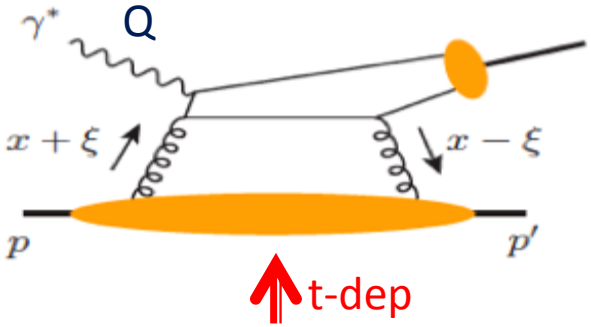


Proton Spin

How about the glue?

Spatial imaging of gluons

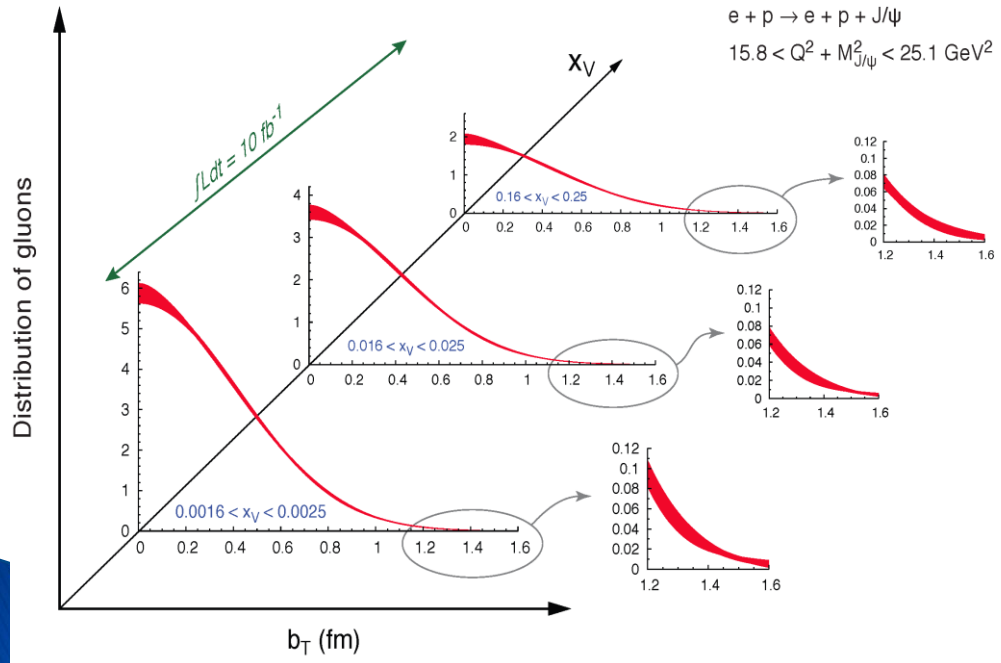
- **Exclusive vector meson production:**

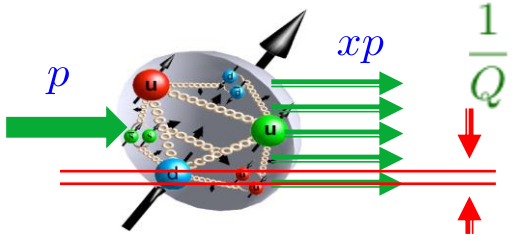


J/Ψ, Φ, …

- ✧ Fourier transform of the t-dep
- ➡ Spatial imaging of glue density
- ✧ Resolution ~ 1/Q or $1/M_Q$

- **Gluon imaging from simulation:**





$$x_V = \frac{M_{J/\psi}^2 + Q^2}{W^2 + Q^2 + M_N^2}$$

$$W^2 = (p+q)^2; \qquad M_N^2 = p^2$$

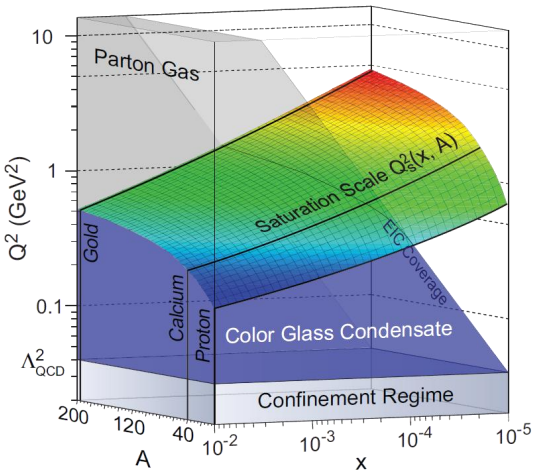
Images of gluons from exclusive J/ψ production

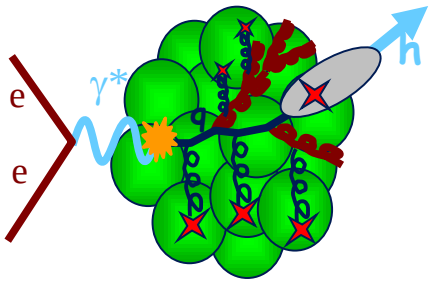
Only possible at the EIC: From the valence quark region deep into the sea quark region

PHENIX

Physics goals 2: nucleus as a laboratory for QCD

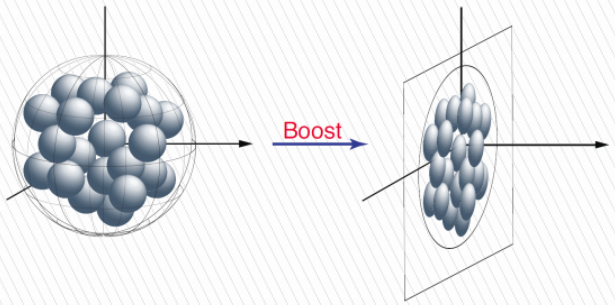
- The compelling questions:
  - Where does the saturation of gluon densities set in?
  - How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?
- Deliverable measurement using electron-ion collisions
  - Probing saturation of gluon using diffractive process
  - Nuclear modification for hadron and heavy flavor production in DIS events
- Leading detector requirement:
  - Large calorimeter coverage to ID diffractive events
  - ID of hadron and heavy flavor production



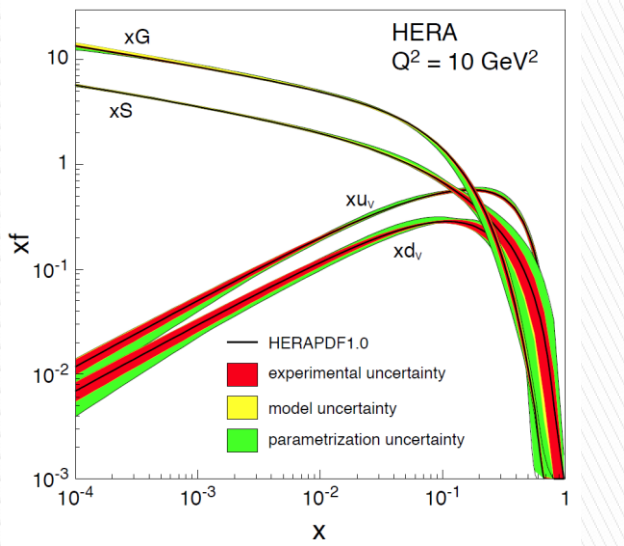


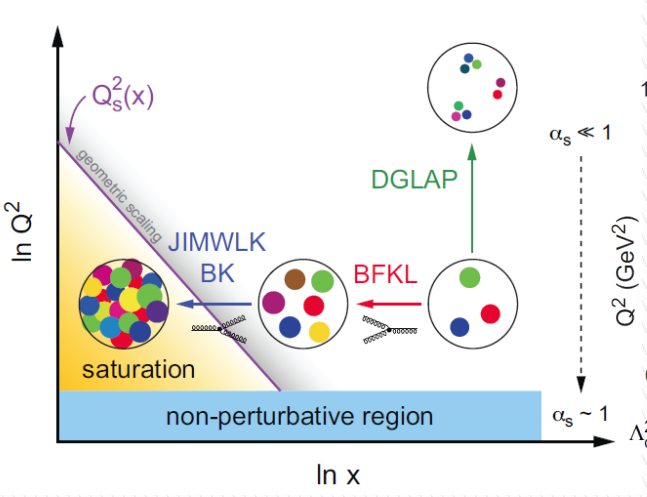
Rising gluon density at small-x leads to a saturation to conserve unitarily

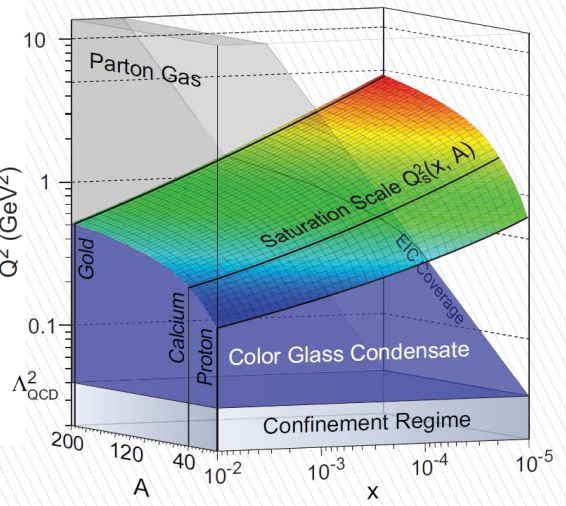
McLerran-Venugopalan Model



$$Q_S^2 \propto A^{1/3} \sim 6(Au)$$





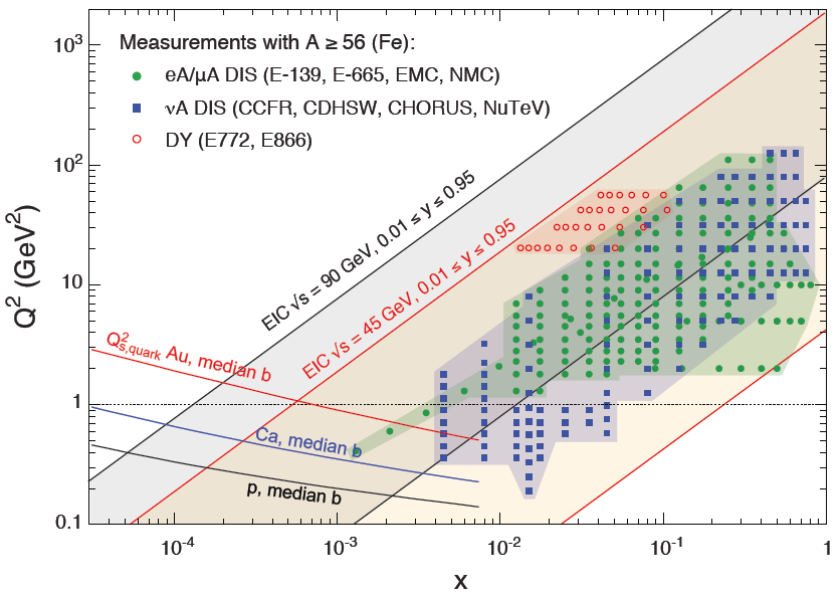


Proton PDF from HERA

Evolution of PDF in x and Q^2

Nuclear dependence

Test in EIC (eA)

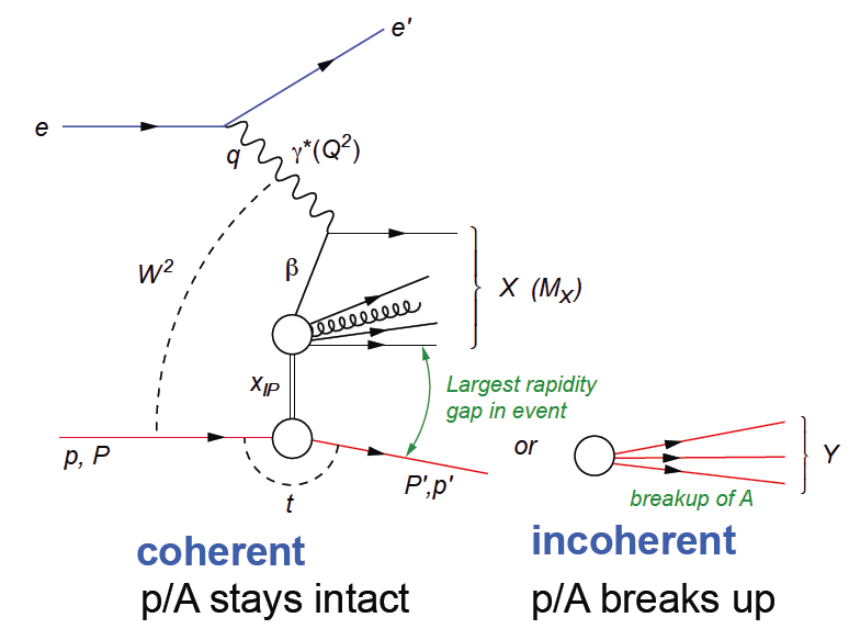


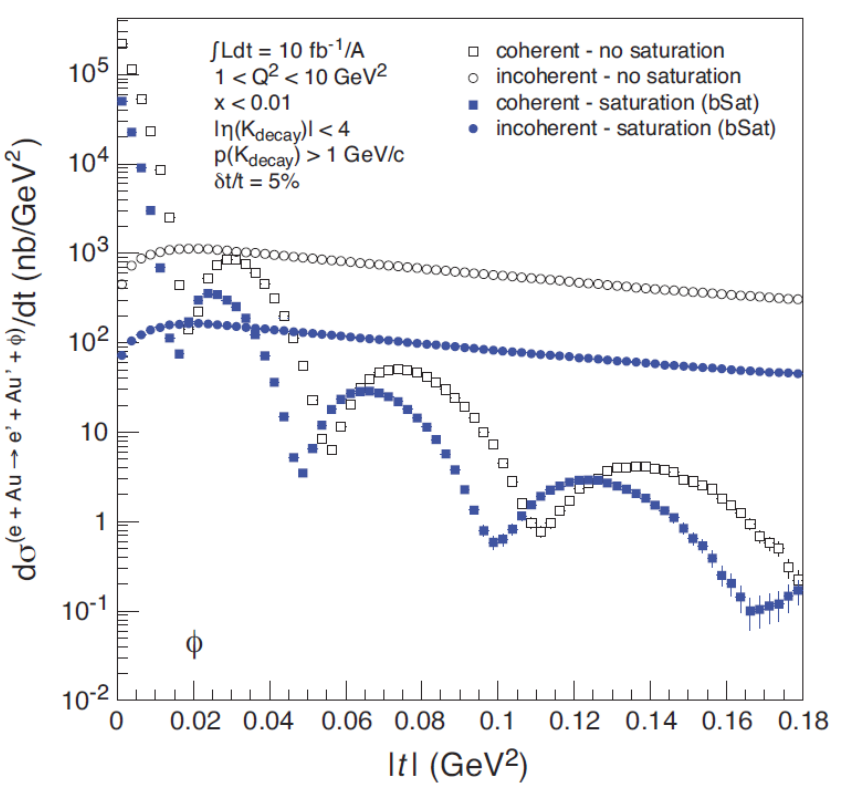
- Direct measurement of structure function F_L
- De-correlation of back-to-back produced particle pairs
- Diffraction process (next page)

Test the model within the reach of kinematics

A set of observable to probe and cross check

Diffractive process



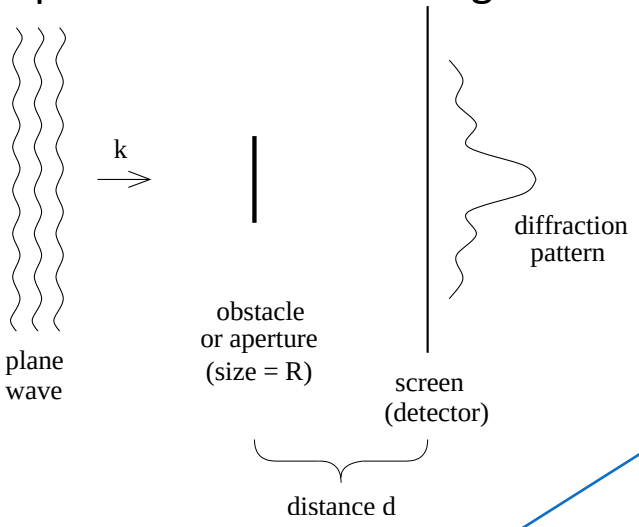


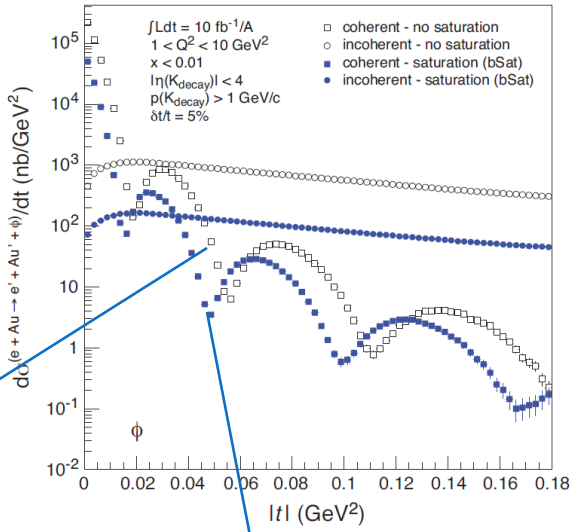
Diffractive production of color less particle through due gluon exchange

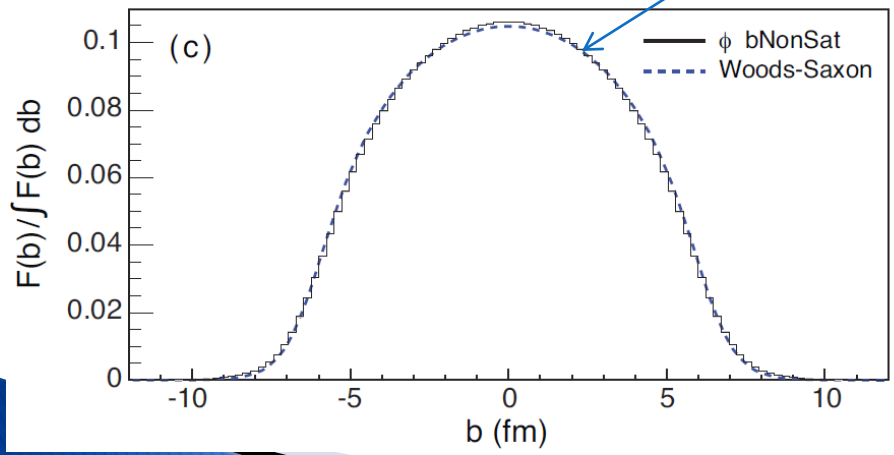
ϕ-cross section difference in models

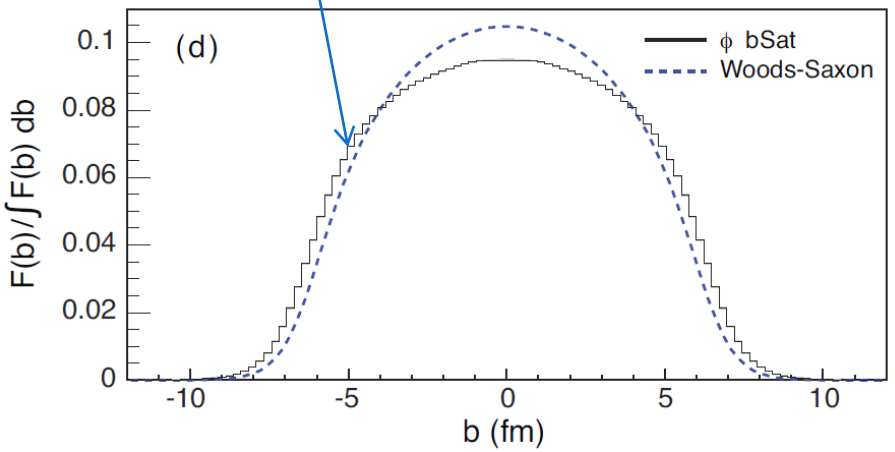
Tomography of gluon distribution in Au

Optical diffraction analog

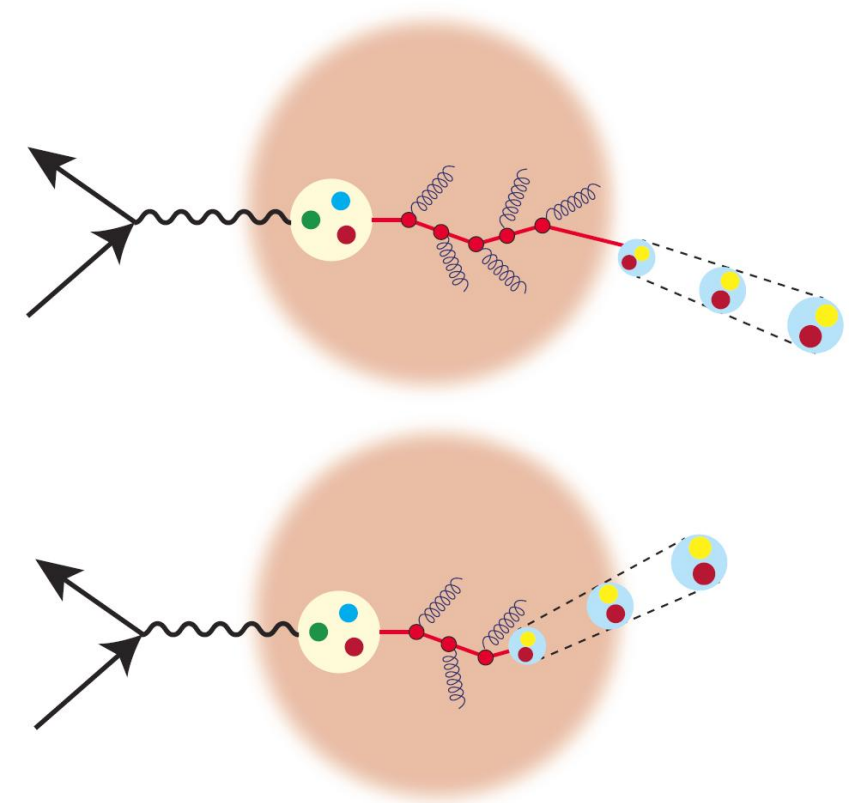








Propagation of quark in nuclear medium



- Besides measuring nPDF
- Probe fast moving color charged object moving through code nuclear matter
- Well controlled kinematics: energy of quark, size of nuclear, species of quark and final state hadron, path length of hadronization
- Study quark energy loss model, modification to hadronization, interaction of hadron an nuclear medium

DIS in nuclear

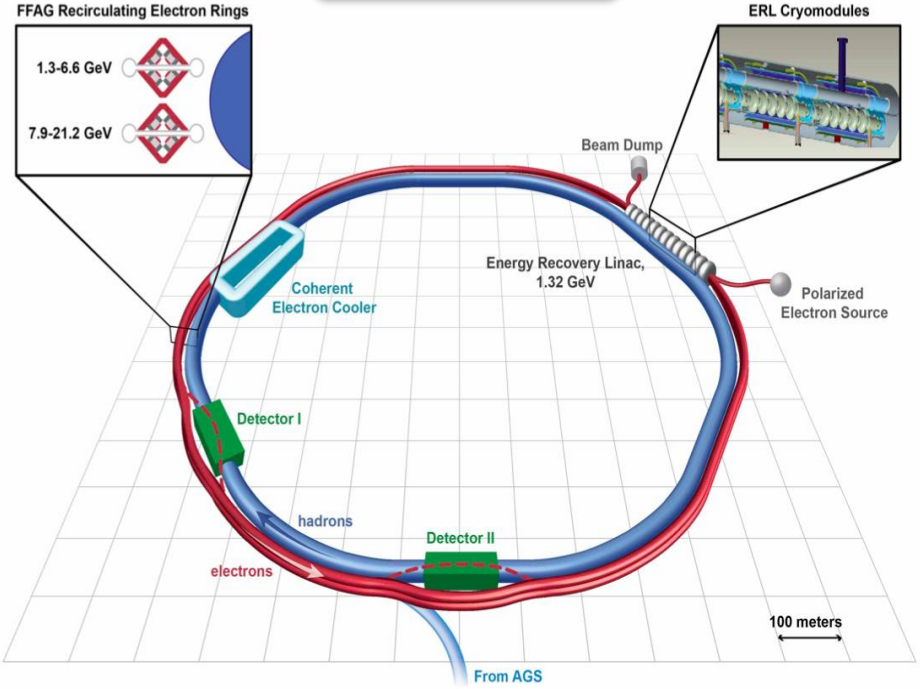
Advantage to study in EIC

Overview on major concepts for EIC facilities and detectors

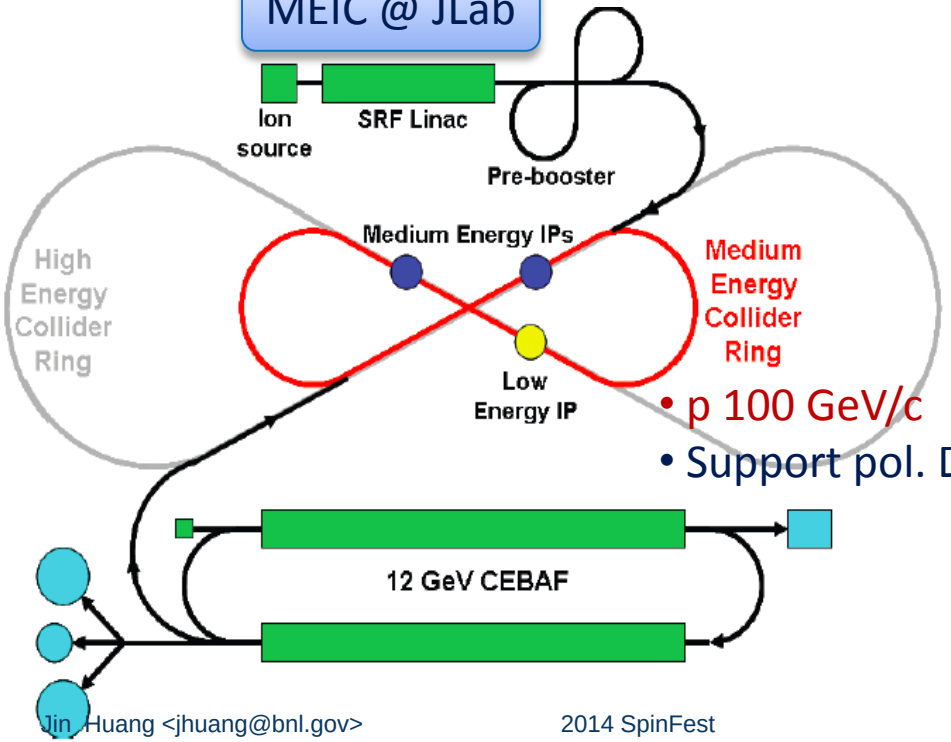
High energy polarized EIC concepts

- Highly polarized electron and nucleon beams
- Ion beams from D-> U or Pb
- Variable C.M. energy from 20 -> 100 GeV (150 upgradable)
- High collision luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$ (HERA luminosity ~ $5x10^{31}$ cm^{-2} s^{-1})
- Possibility of more than one interaction regions

eRHIC @ BNL

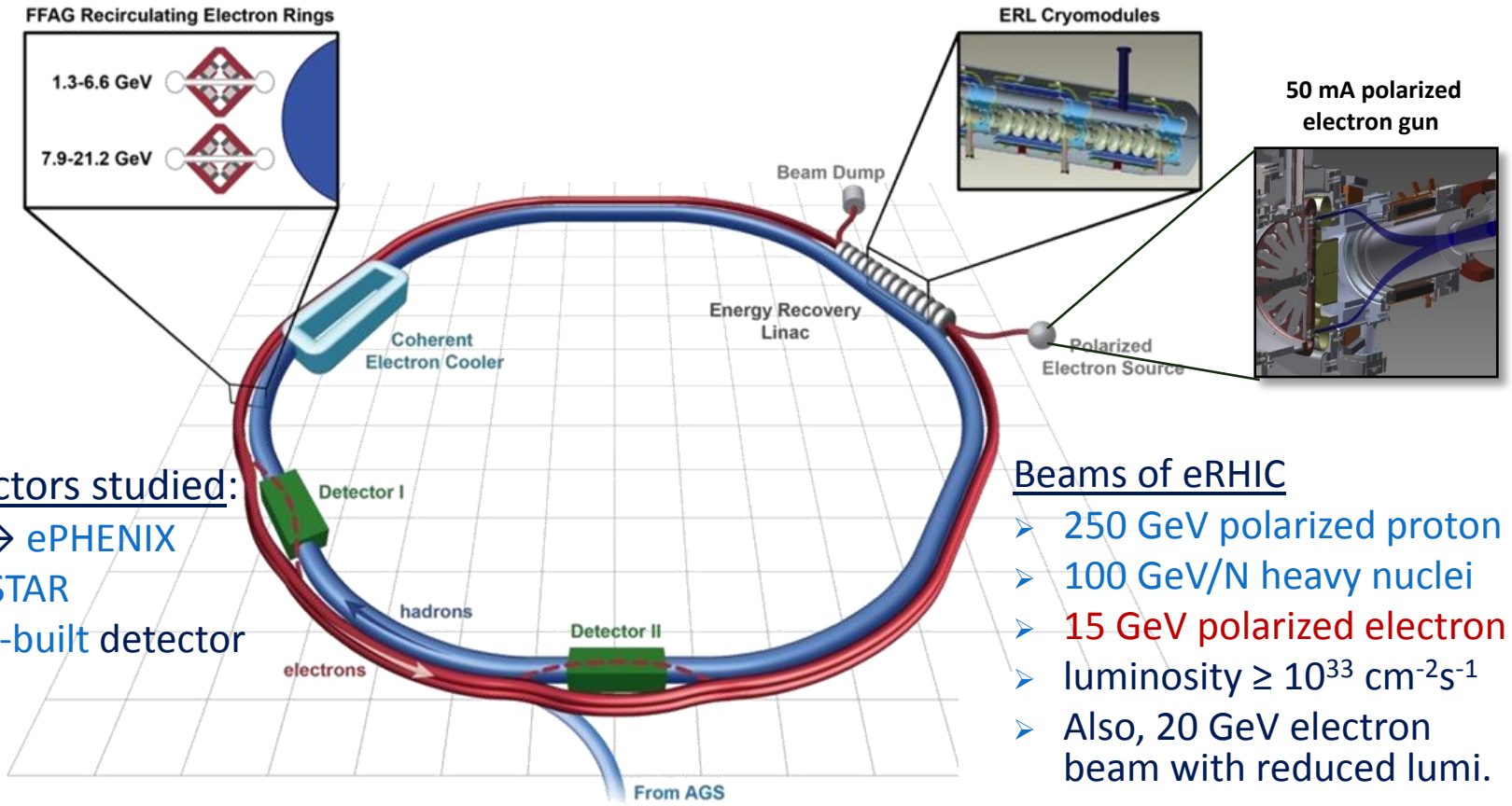


MEIC @ JLab



RHIC → eRHIC around year 2025
One realization of electron ion collider:

eRHIC: reuse one of the RHIC rings + high intensity electron energy recovery linearc



Possible detectors studied:

- sPHENIX → ePHENIX
- STAR → eSTAR
- A purpose-built detector

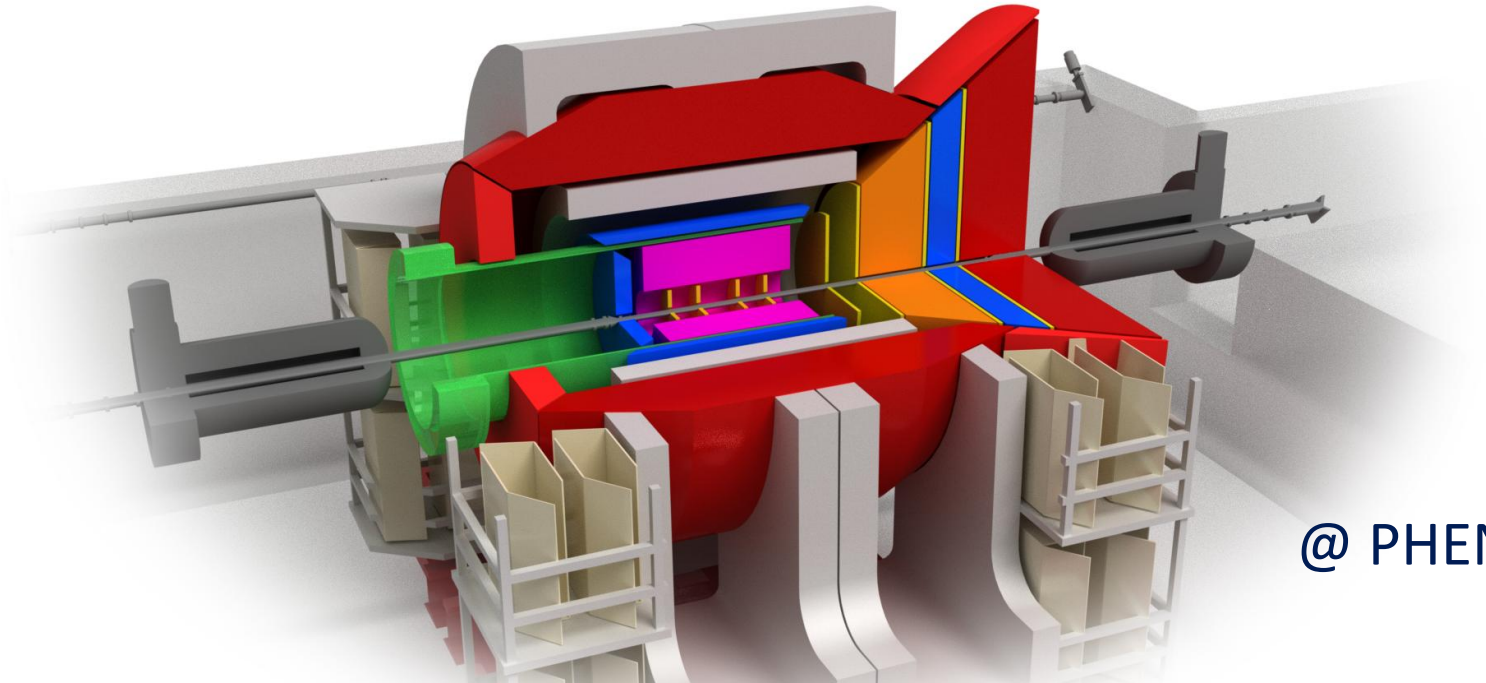
Beams of eRHIC

- 250 GeV polarized proton
- 100 GeV/N heavy nuclei
- 15 GeV polarized electron
- luminosity ≥ 10^{33} $cm^{-2}s^{-1}$
- Also, 20 GeV electron beam with reduced lumi.

Courtesy: eRHIC pre-CDR
BNL CA-D department

BaBar-based detector concept

More details in the next session of this lecture

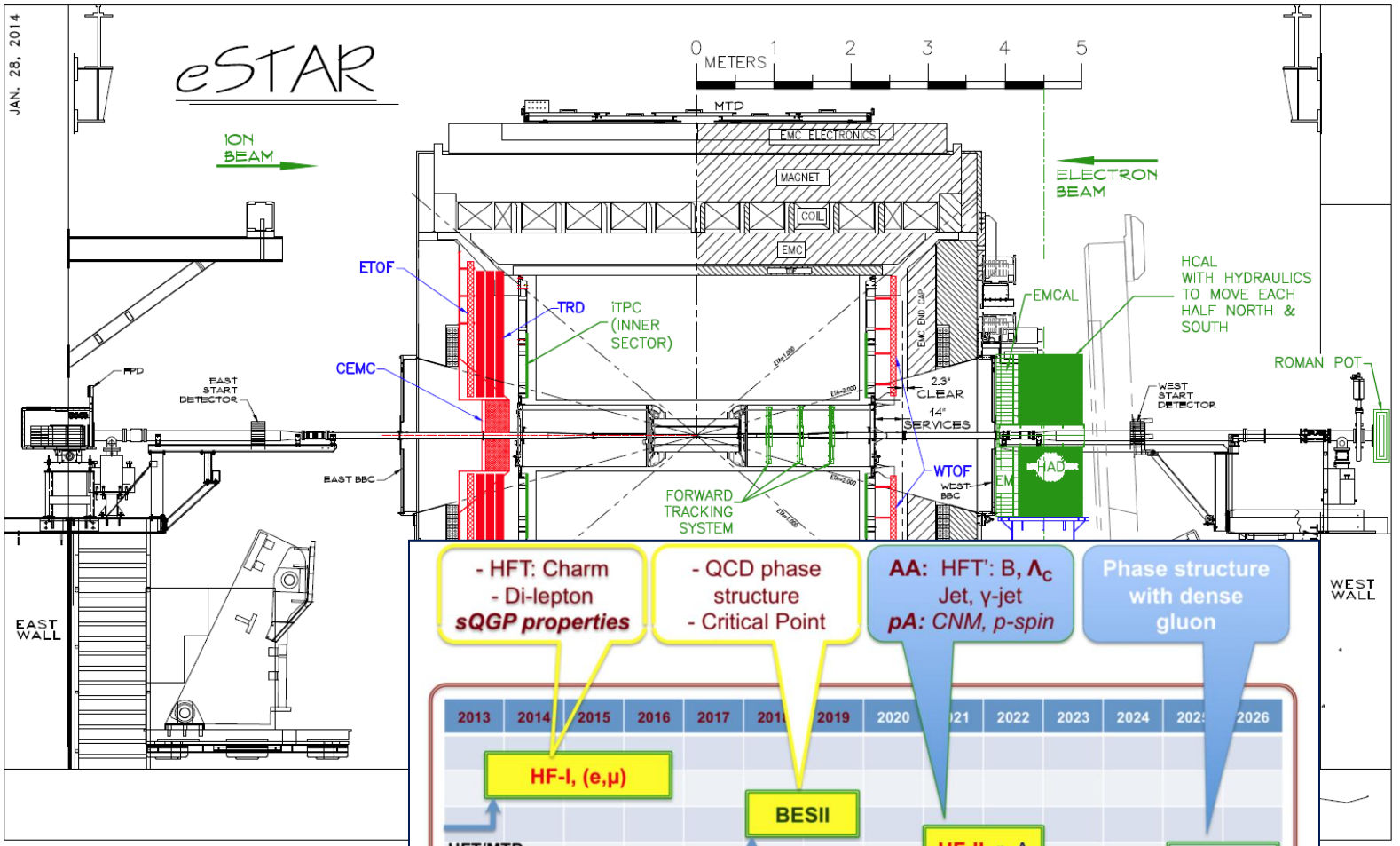


@ PHENIX Hall

- PHENIX @ 2025+: a comprehensive day-one eRHIC detector for studying nucleon structure and dense nuclear matter
- An upgrade path that harvests **pp, pA and AA** physics and leads to an EIC era

STAR -> eSTAR

Courtesy: eSTAR LOI
eRHIC pre-CDR



A purpose-built eRHIC detector

Solenoidal magnetic field with high precision silicon and GEM tracking

Lepton-ID:

-3 <η< 3: e/p

1 <|η|< 3: Hcal

3 <|η|< 4: Ecal & Hcal

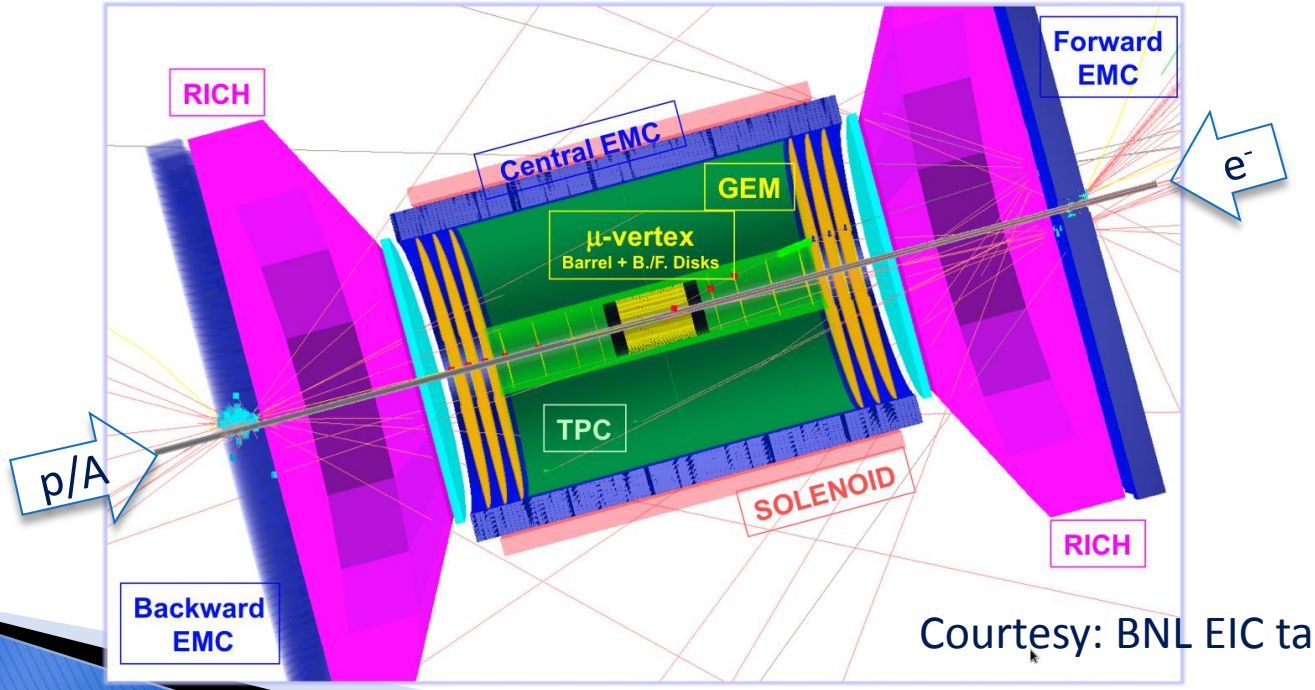
|η|< 4: γ suppression via tracking

hadron PID:

1<|η|<3: RICH

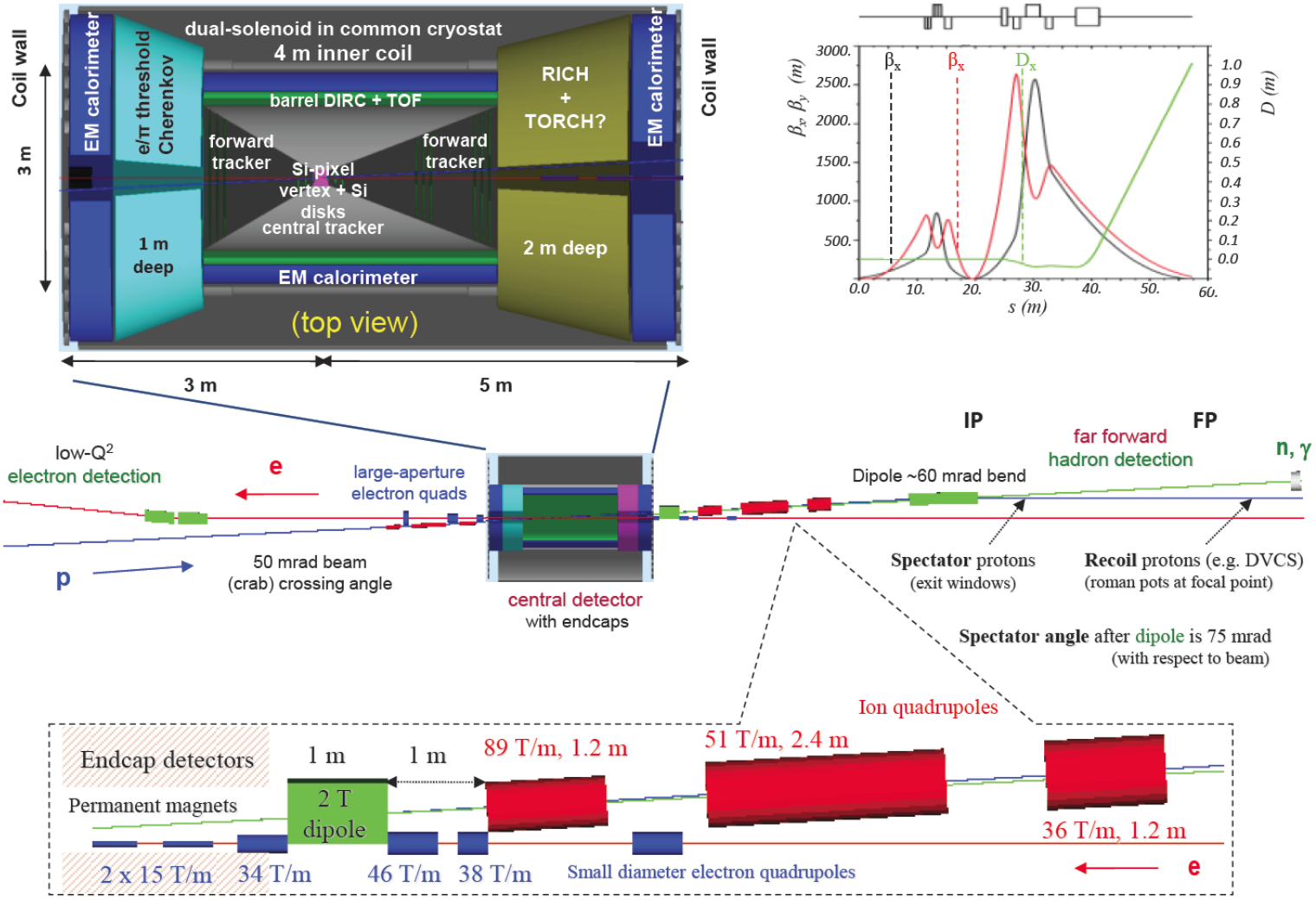
-1<η<1: TPC (dE/dx)

Central rapidities PID possiblities:
DIRC, Time-of-Flight,
proximity focusing Aerogel-RICH, …



Courtesy: BNL EIC taskforce

mEIC detector at Jefferson Lab [arXiv:1212.1701]



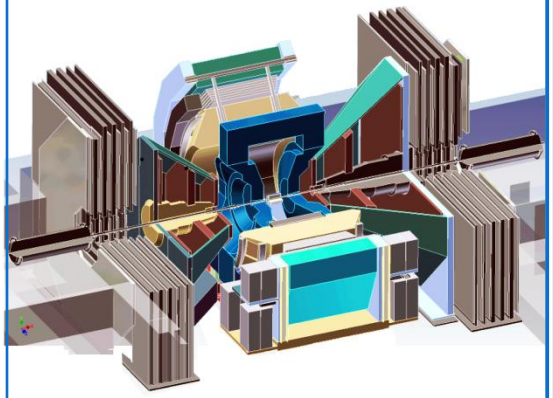
PHENIX -> sPHENIX -> An EIC detector

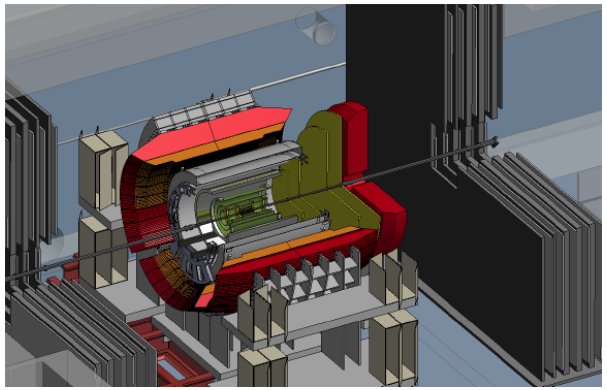
- Many people's work over multiple years
- Letter-of-intent : arXiv:1402.1209 outlining one feasible concept
- An experiment you can design and build rather than built for you!

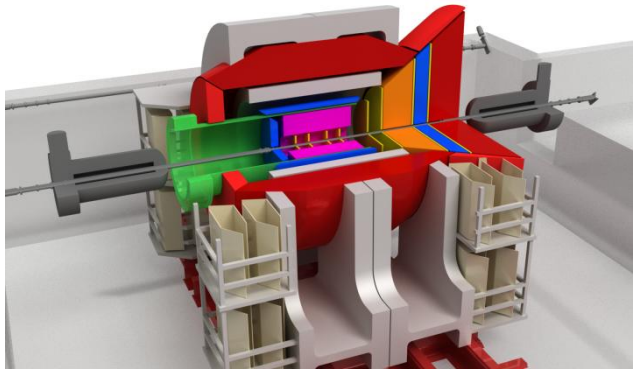
PHENIX -> ePHENIX

Documented: http://www.phenix.bnl.gov/plans.html

Current PHENIX	*f/s*PHENIX	An EIC detector
▸ Current PHENIX as discussed in many previous talks ▸ 14y+ work 100+M$ investment ▸ 130+ published papers to date ▸ Last run in this form 2016	▸ Comprehensive central upgrade base on BaBar magnet ▸ fsPHENIX : forward tracking, Hcal and muon ID ▸ Key tests of theoretical frameworks for transverse spin	▸ Path of PHENIX upgrade leads to a capable EIC detector ▸ Large coverage of tracking, calorimetry and PID ▸ Open for new collaboration/new ideas







~2000 2017→2020 ~2025 Time

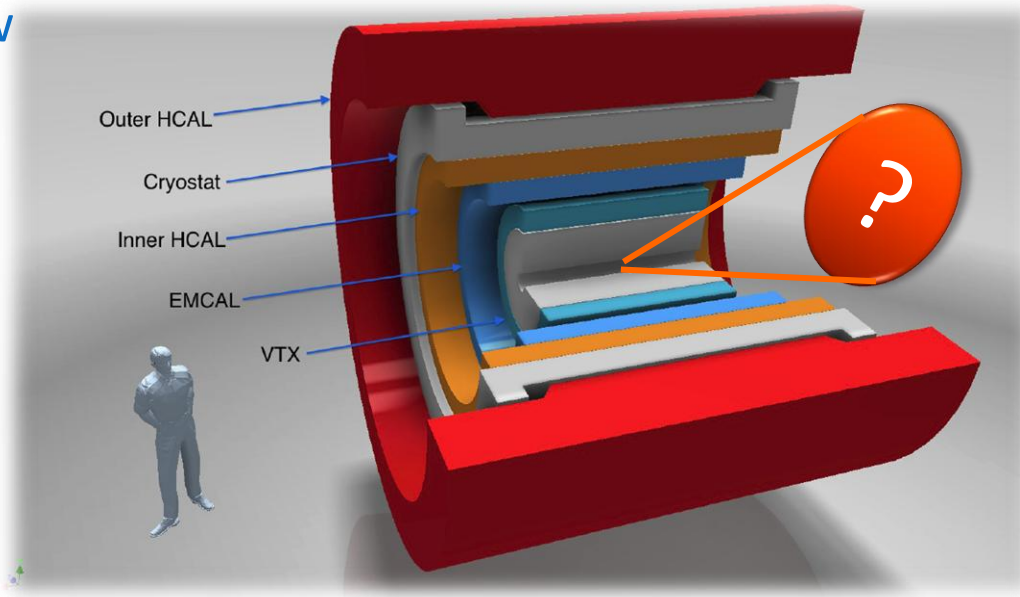
RHIC: A+A, spin-polarized p+p, spin-polarized p+A

eRHIC: e+p, e+A

The sPHENIX detector

Details in lecture: Dave Morrison

- sPHENIX: major upgrade to the PHENIX experiment aim for data @ 2020
- Physics Goals: detailed study QGP using jets and heavy quarks at RHIC energy region
- Baseline consists of new large acceptance EMCal+HCal built around recently acquired BaBar magnet. Additional tracking also planned
- Successful DOE scientific review three weeks ago
- A good foundation for future detector upgrade

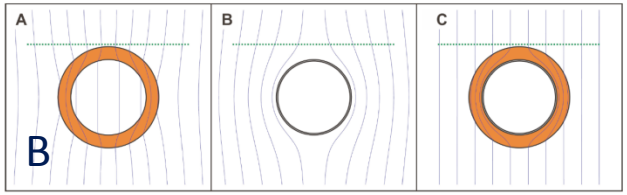


Baseline detectors for sPHENIX

sPHENIX MIE, http://www.phenix.bnl.gov/plans.html

What field shall we add in the forward? - Brain storm in the past few years

Design Family	Example
Piston	• Passive piston (C. L. da Silva) • Super conducting piston (Y. Goto)
Dipole	• Forward dipole (Y. Goto, A. Deshpande, et. al.) • Redirect magnetic flux of solenoid (T. Hemmick) • Use less-magnetic material for a azimuthal portion of central H-Cal (E. Kistenev)
Toroid	• Air core toroid (E. Kistenev) • Six fold toroid (J. Huang)
Other axial symmetric Field shaper	• Large field solenoidal extension (C. L. da Silva) • Pancake field pusher (T. Hemmick)

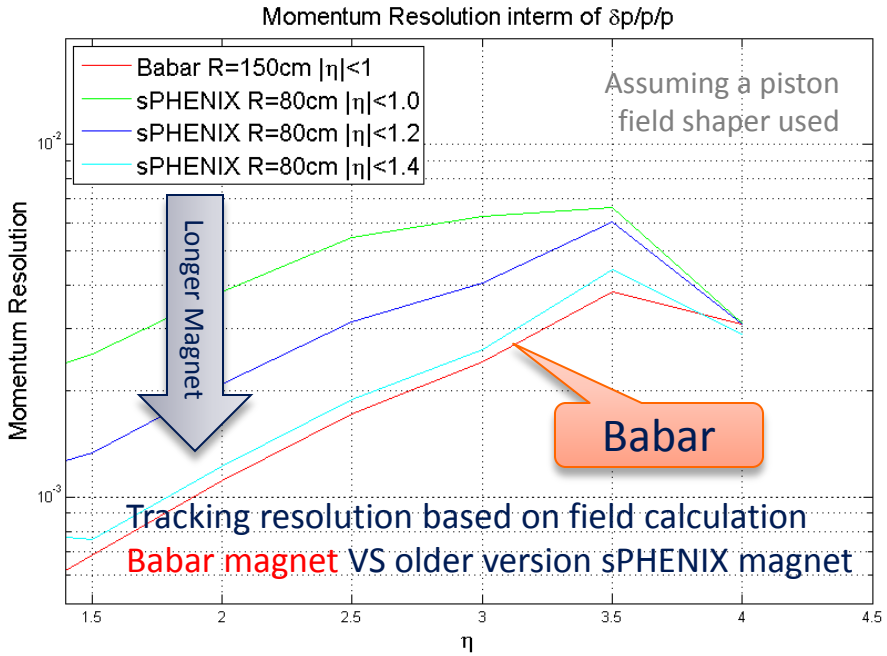


Beam line magnetic field shielding, based on superconducting pipe. From Nils F.

BaBar Coil

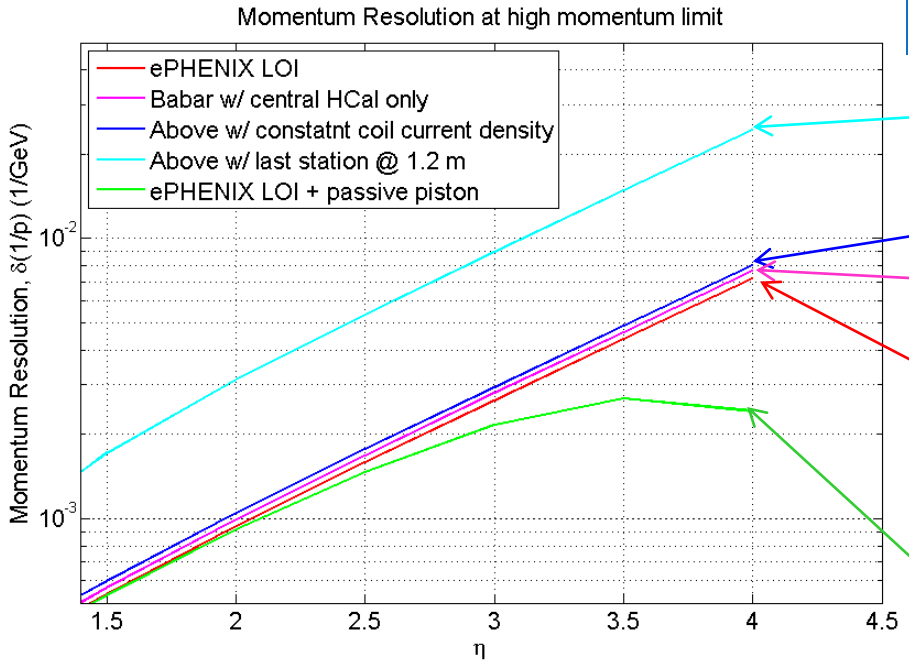
- Field concept
  - Central field: solenoidal as sPHENIX design
  - Forward field: Went through ~10 types of magnet design over few years
- BaBar superconducting magnet became available
  - Built by Ansaldo → SLAC ~1999
  - Nominal field: 1.5T
  - Radius : 140-173 cm; Length: 385 cm
- Field calculation and yoke tuning
  - Three field calculator cross checked: POISSION (Thanks to Paul's SoLID design), FEM and OPERA
- Favor for ePHENIX tracking
  - Designed for homogeneous B-field in central tracking
  - Longer field volume for forward tracking
  - Higher current density at end of the magnet -> better forward bending
  - Work well with RICH in ePHENIX yoke: Forward & central Hcal + Steel lampshade
- Ownership officially transferred to BNL, prepare shipping

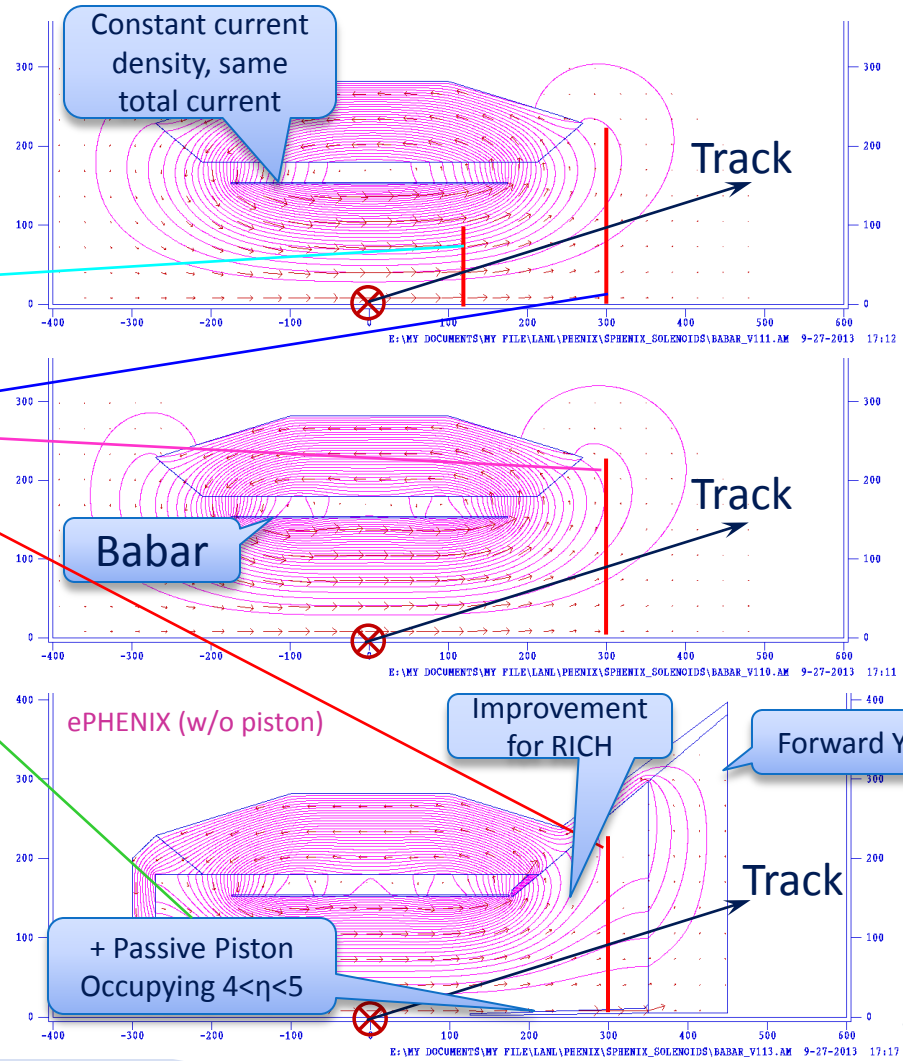

BaBar solenoid packed for shipping, May 17 2013



Considerations for yoke and tracking designs

- Optimal tracking configurations
  - Measure sagitta with vertex – optimal sagitta plane (not drawn) – last tracking station
  - Yoke after tracking space and conform with a |z|<4.5m limit
- ePHENIX LOI
  - Central + forward yoke (hadron calo.)
  - Last tracking station at z=3.0m

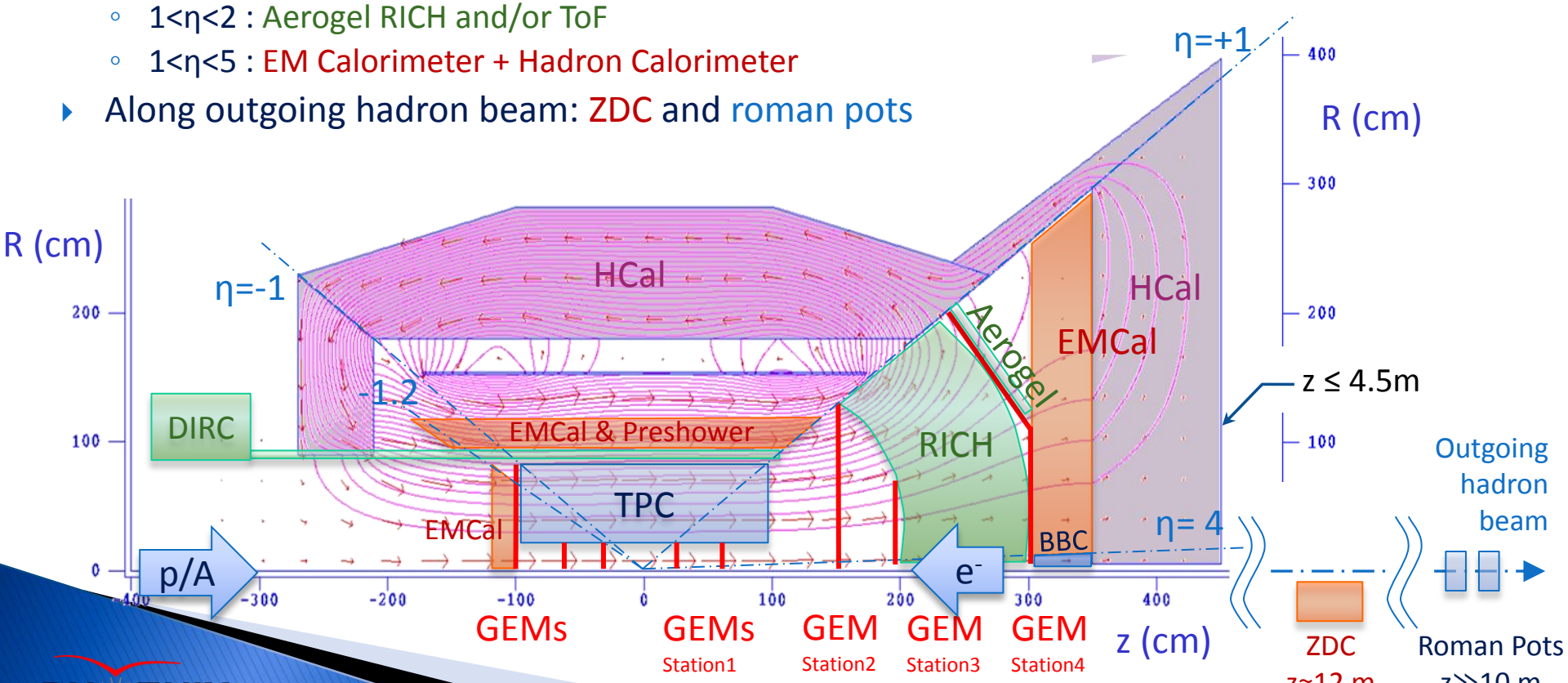




In eRHIC era: concept for an EIC Detector

- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC
- -4<η<-1 (e-going) :
  High resolution calorimeter + GEM trackers
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH
  - 1<η<2 : Aerogel RICH and/or ToF
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots

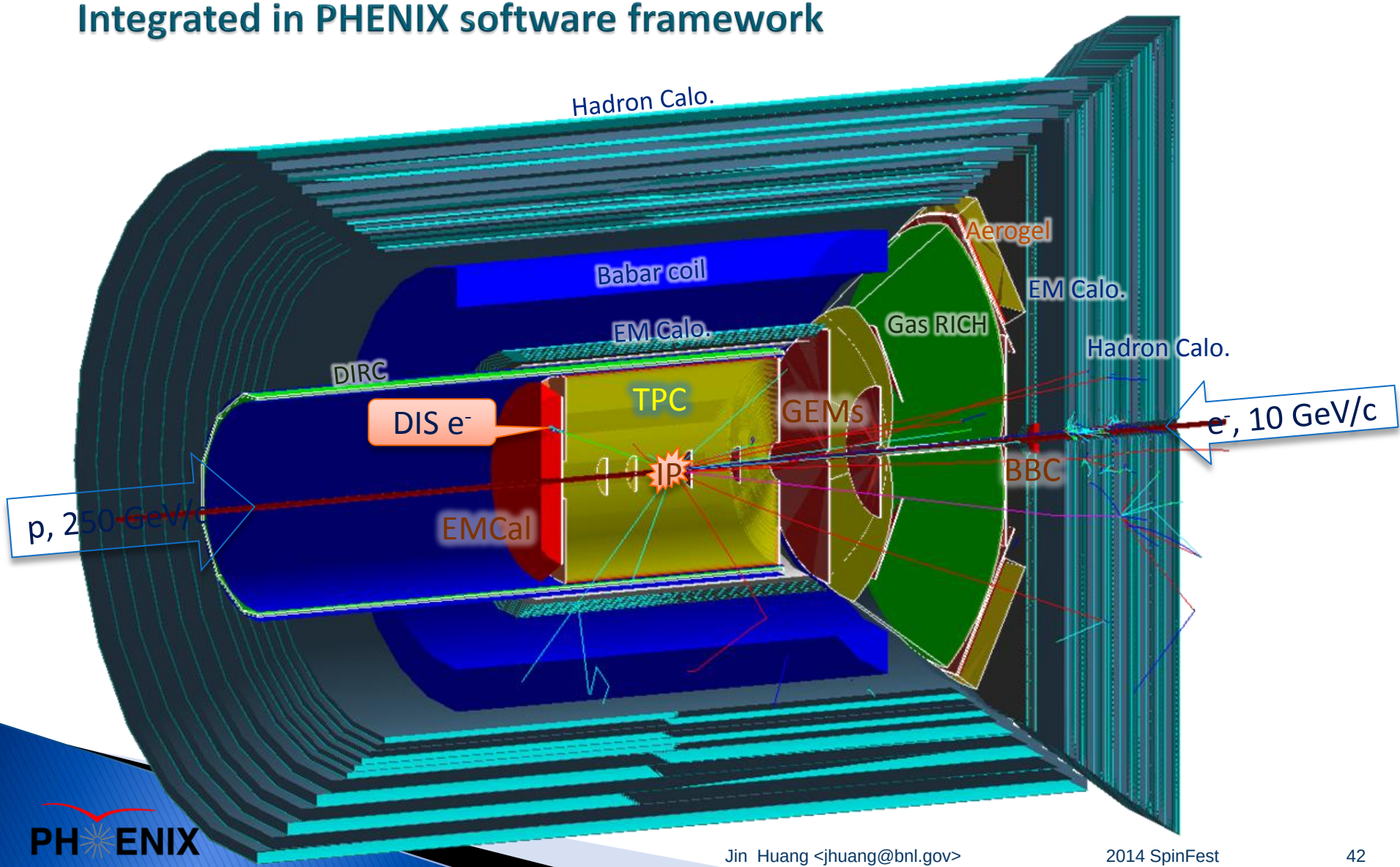
Working title: "ePHENIX"
LOI: arXiv:1402.1209
Review: "good day-one detector"
"solid foundation for future upgrades"



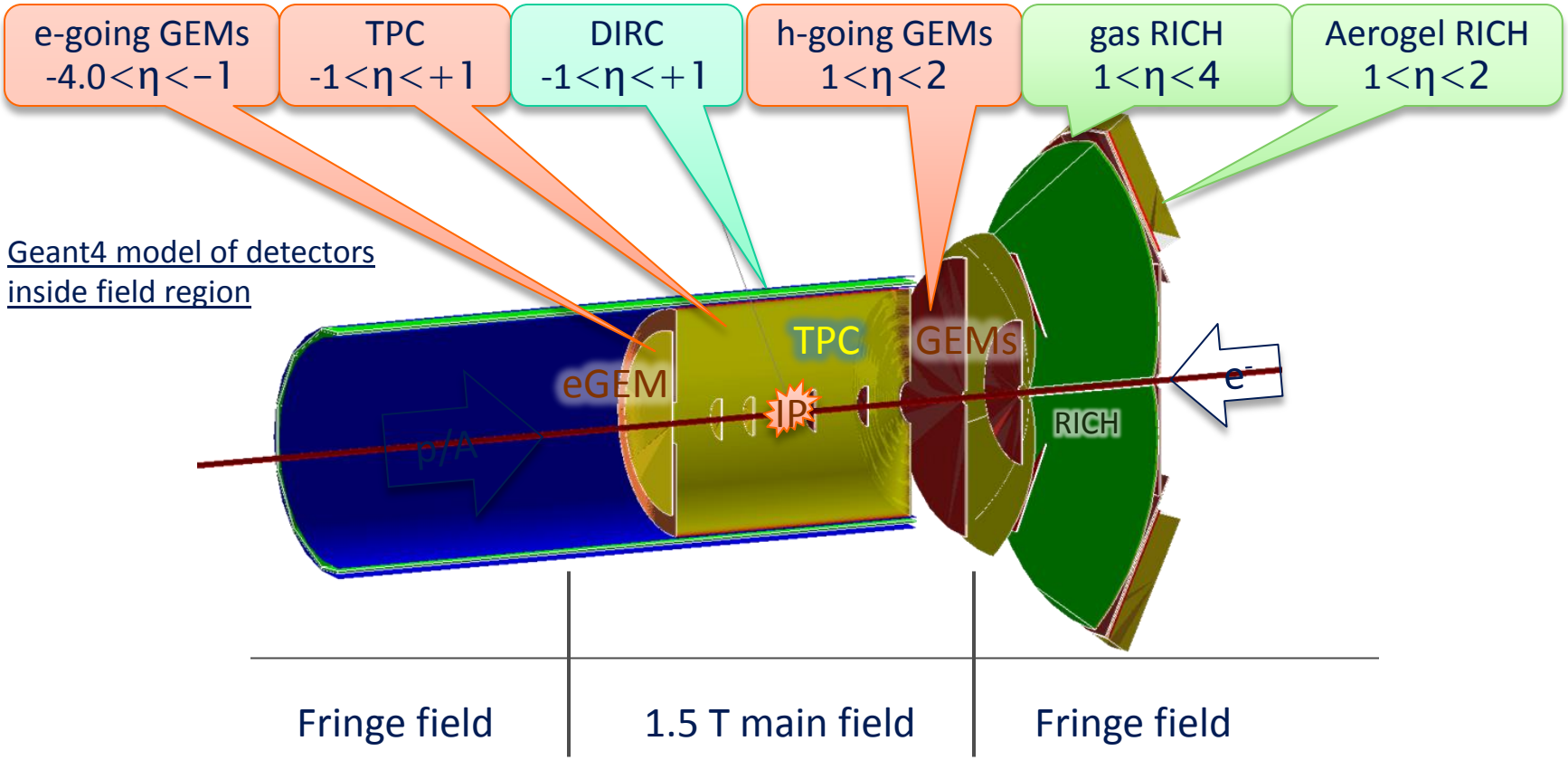
A SIDIS event in ePHENIX

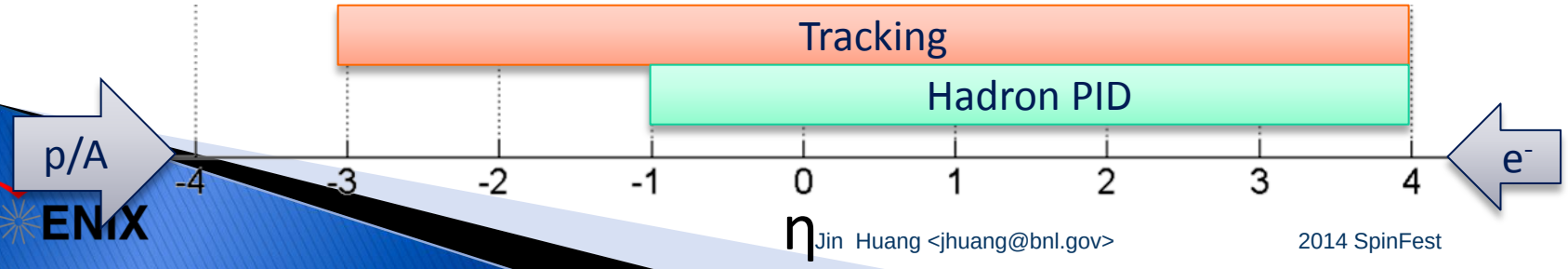
GEANT4 event display for SIDIS @ $x \approx 5\times10^{-3}$ and $Q^2=10$ $(GeV/c)^2$

Integrated in PHENIX software framework



Tracking and PID detector overview

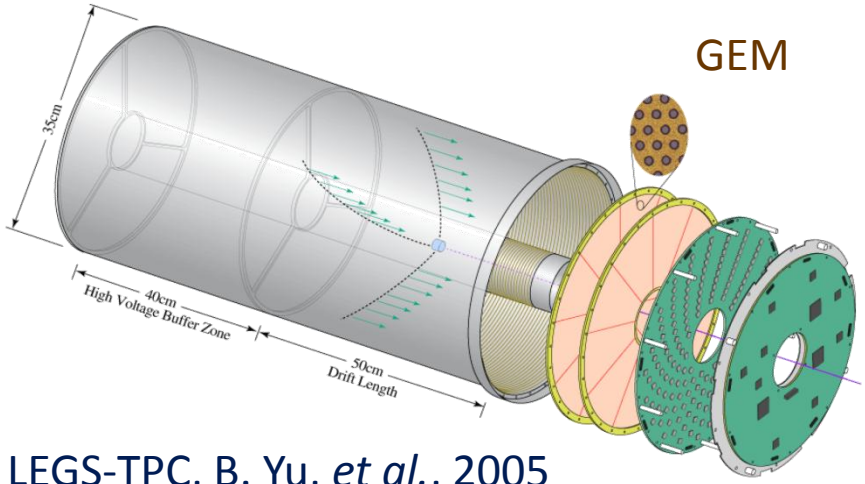




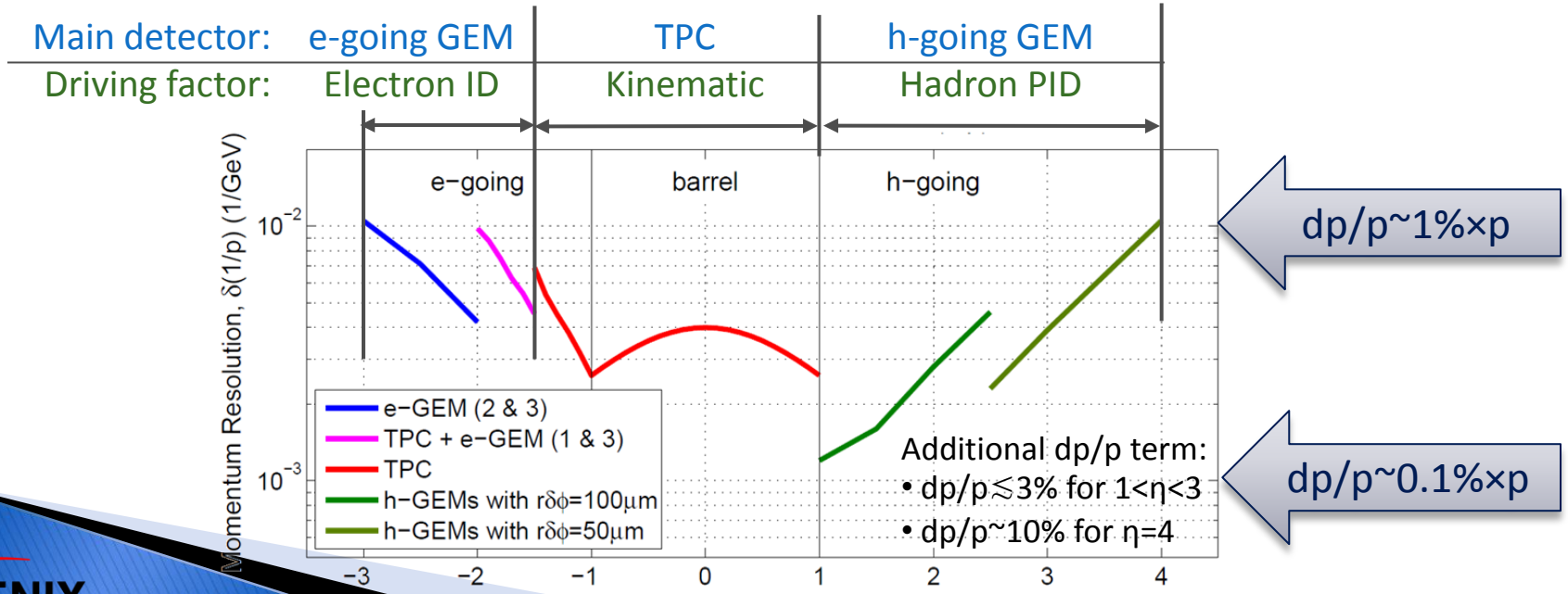
Tracking system

- Good momentum resolution over wide range, -3<η<+4
- GEM tracker for forward region
  - d(rϕ) = 100 μm; 50 μm for very forward region
- GEM-based TPC for barrel region
  - 10μs max drift time and no-gate needed
  - Thin support structure, e.g. fibre-reinforced polymer
- Space available for inner silicon tracker upgrade

GEM

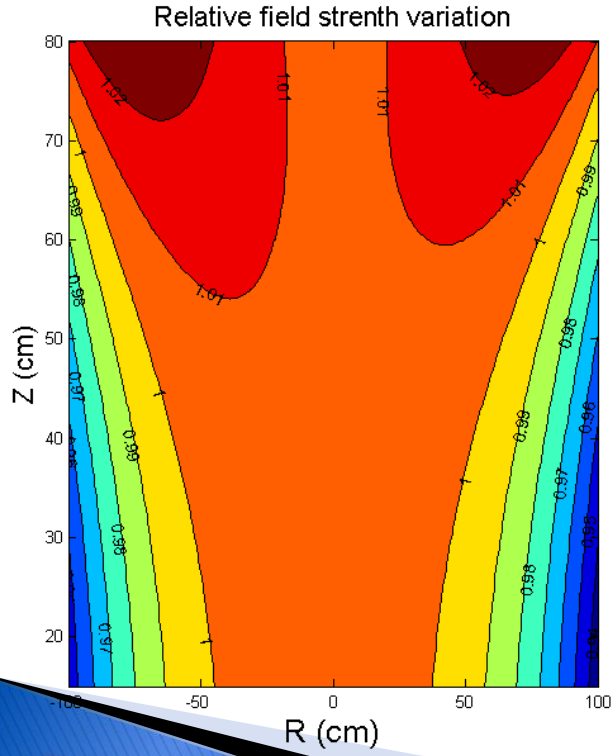


LEGS-TPC, B. Yu, *et al.*, 2005



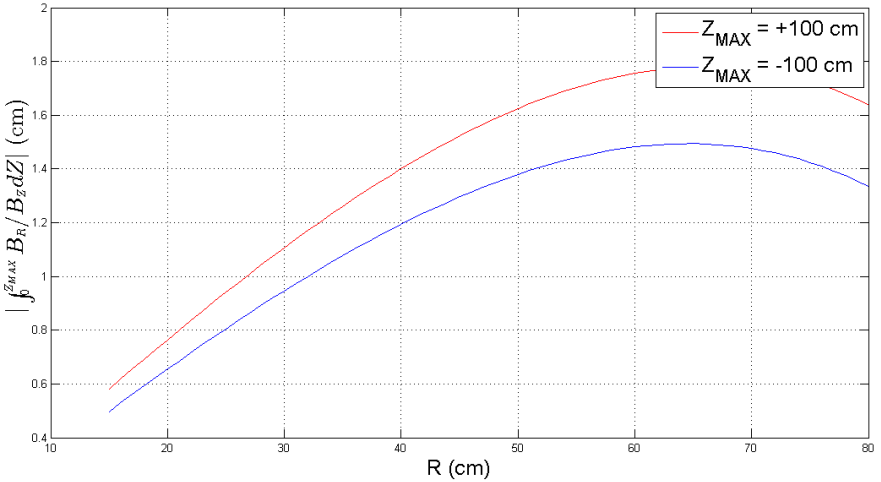
Field effect - TPC drift effect and Correction

- Ideally, magnetic field along z axis for TPCs. $B_{X/Y}$ terms → corrections
- Field map can reach quoted uniformity for Babar (±3% for central tracking volume) by some tuning on the yoke
- Residual distortion on Rϕ should be calibrated and corrected in Reco.



→ Field correction ≲ few mm in Rϕ

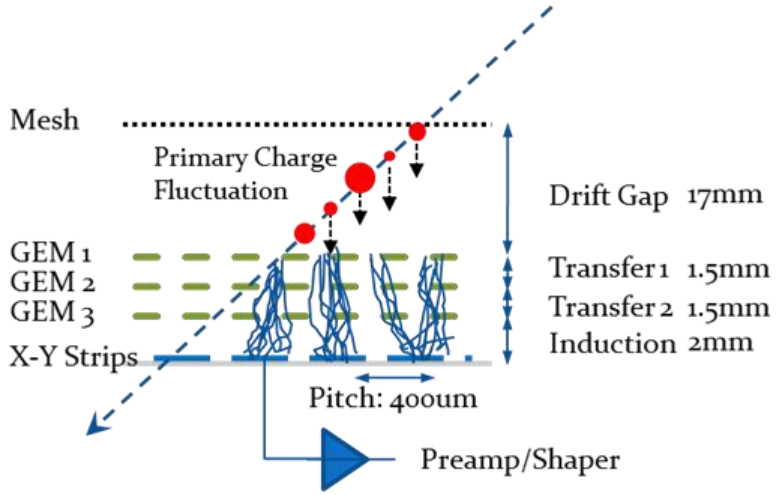
Will apply correction in offline analysis



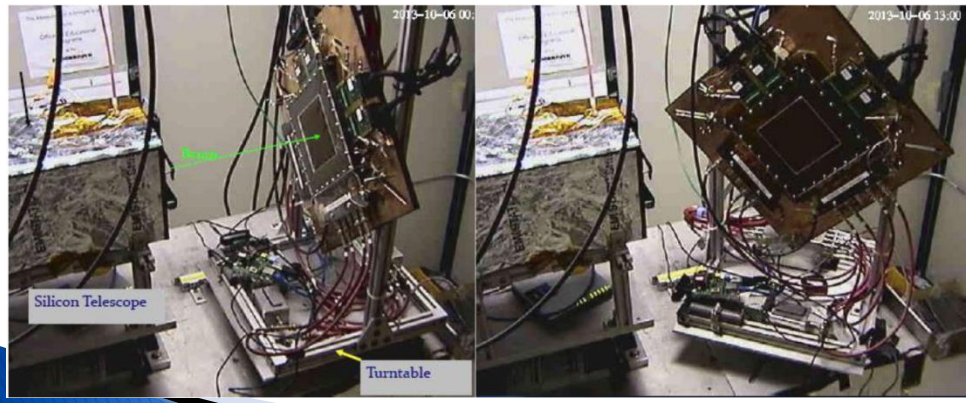
On-going detector R&D : mini-Drift GEM

Courtesy : EIC RD6 TRACKING & PID CONSORTIUM

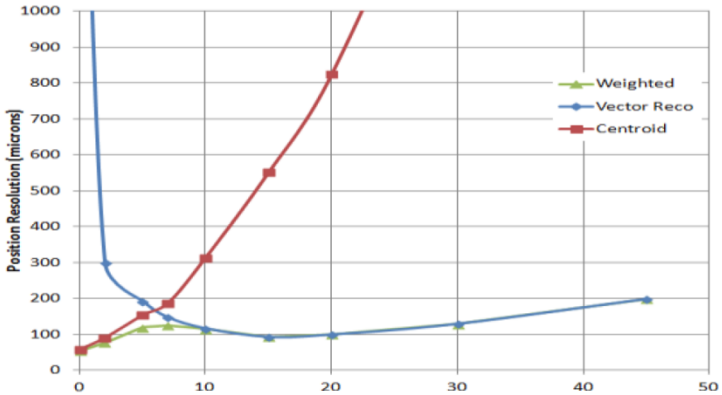
- Challenge in GEM tracking to achieve high precession with large indenting angle in the lower η region
- One of innovation: use thicker drift gap in GEM as a mini-TPC and measure the tracklet
- Successful test beam data for mini-Drift GEM
- Success large area GEM developments



Beam test in Fermi-Lab: October 2013

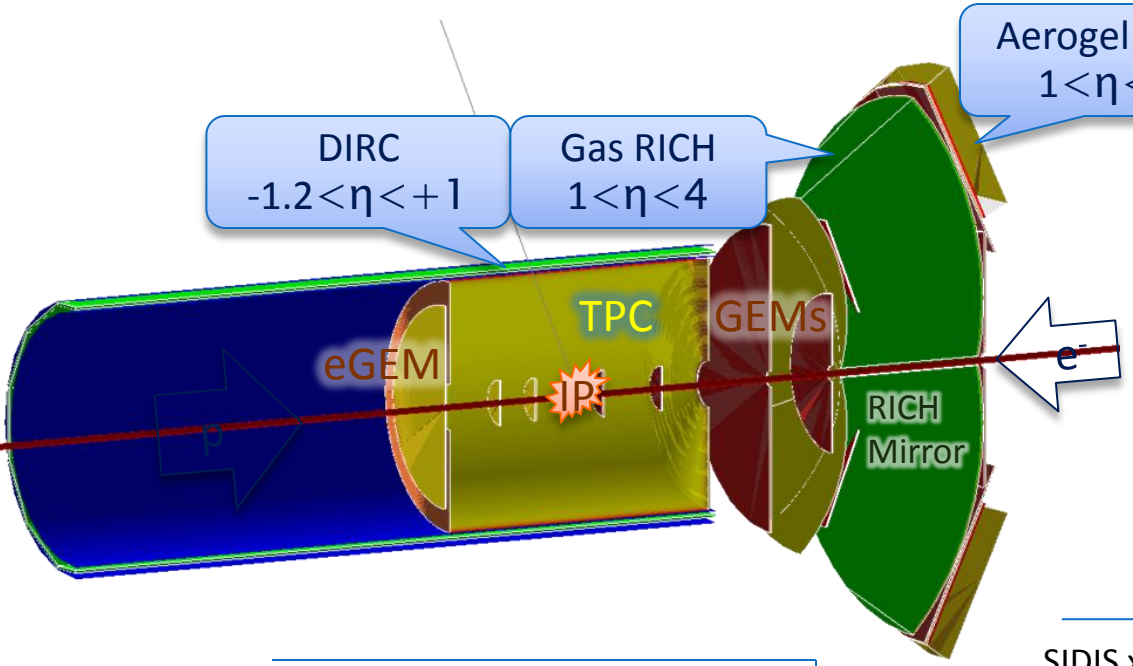


Retain high position resolution using mini-Drift GEM

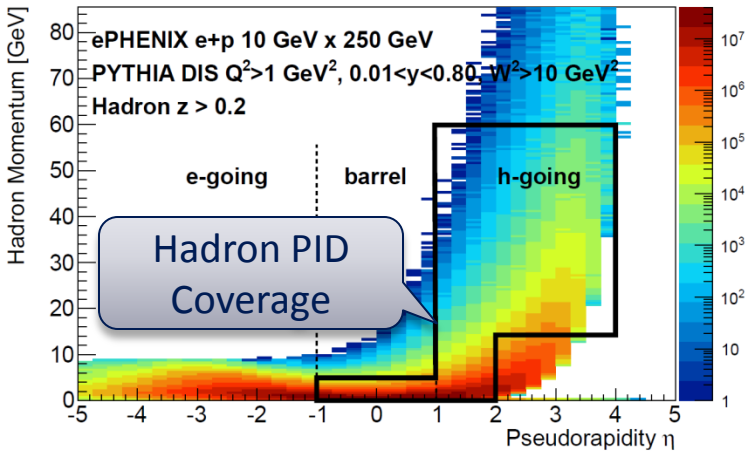


Beam incident angle (degree)

Hadron PID Overview

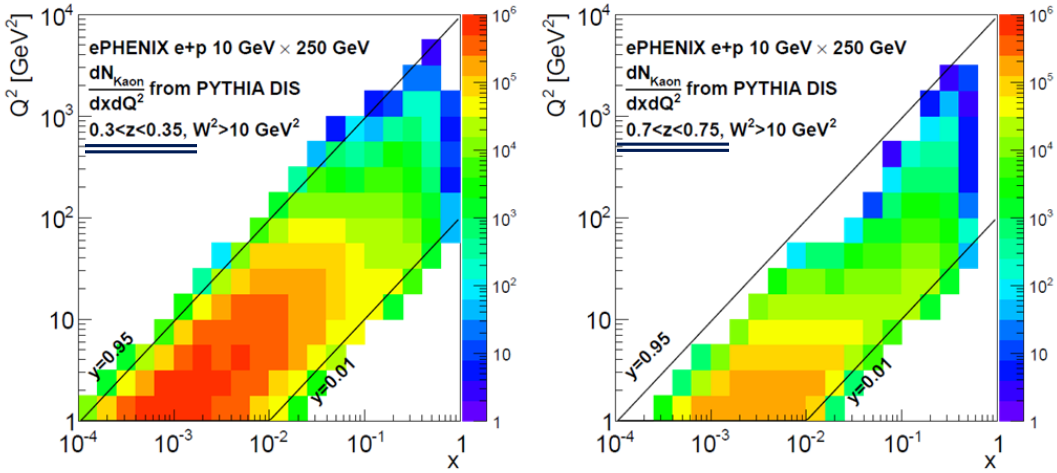


Detector coverage for hadron PID

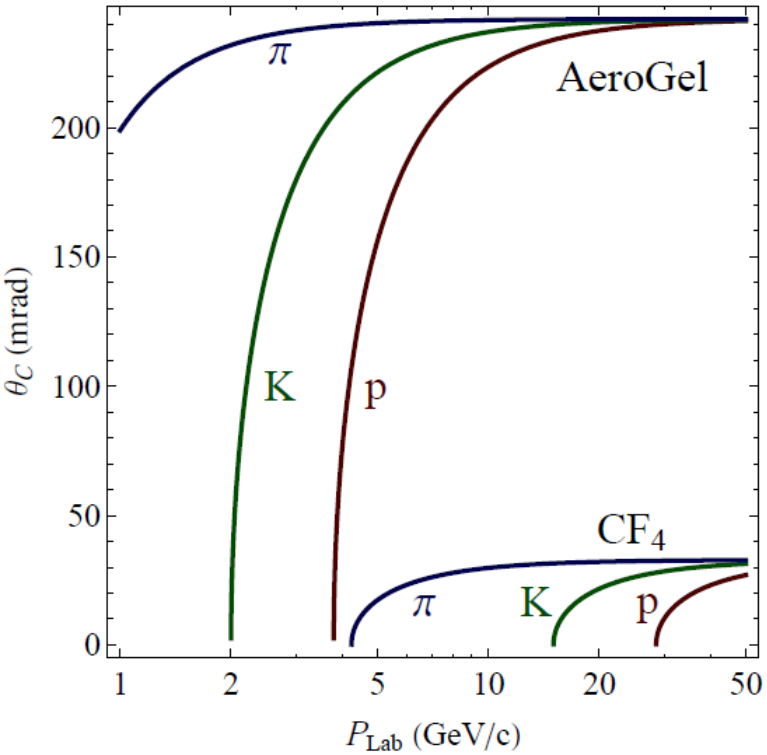


- DIRC
  - Based on BaBar DIRC design plus compact readout
  - Collaborate with TPC dE/dx for hadron ID in central barrel
- Aerogel RICH
  - Approximate focusing design as proposed by Belle-II
  - Collaborate with gas RICH to cover 1<η<2
- Gas RICH: next slides
- Possible upgrade in electron-going direction

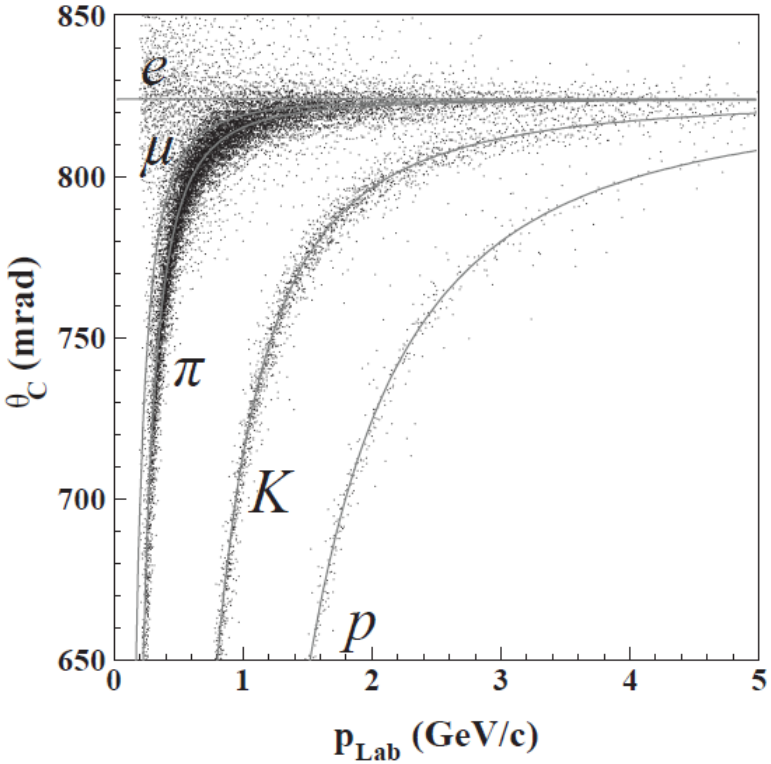
SIDIS x-Q^2 coverage with hadron PID in two z-bins



Cherenkov angles choices



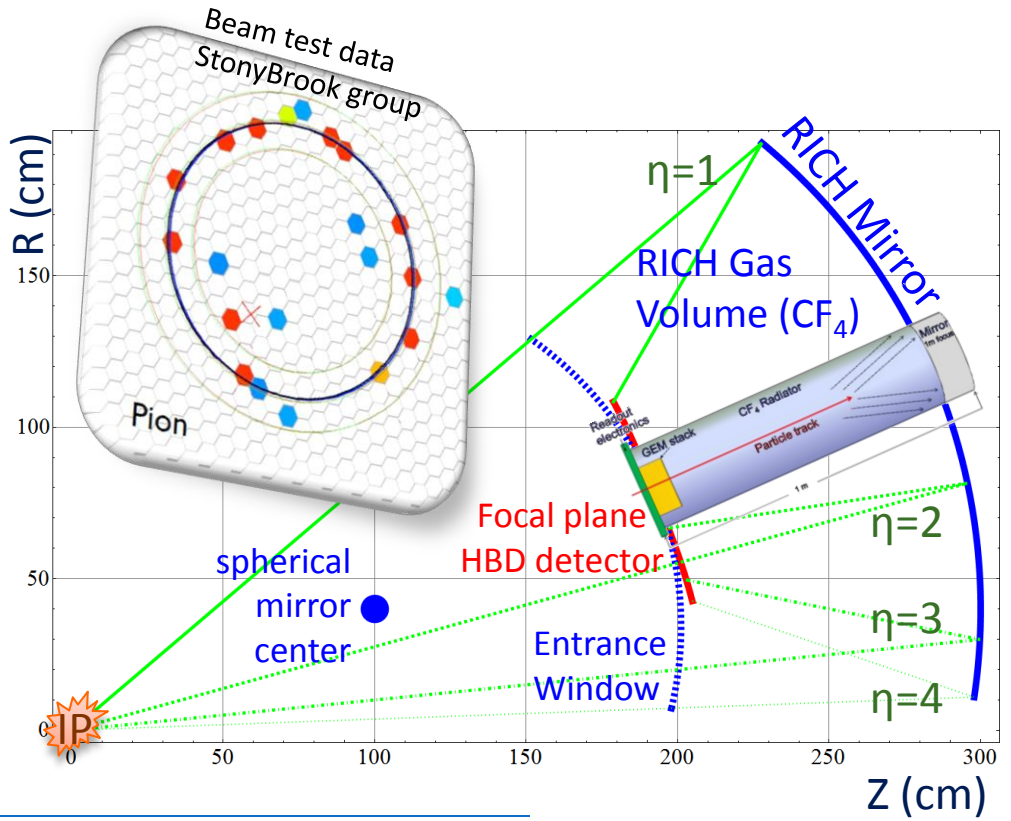
(a) Aerogel and RICH gas radiators for hadron-going direction



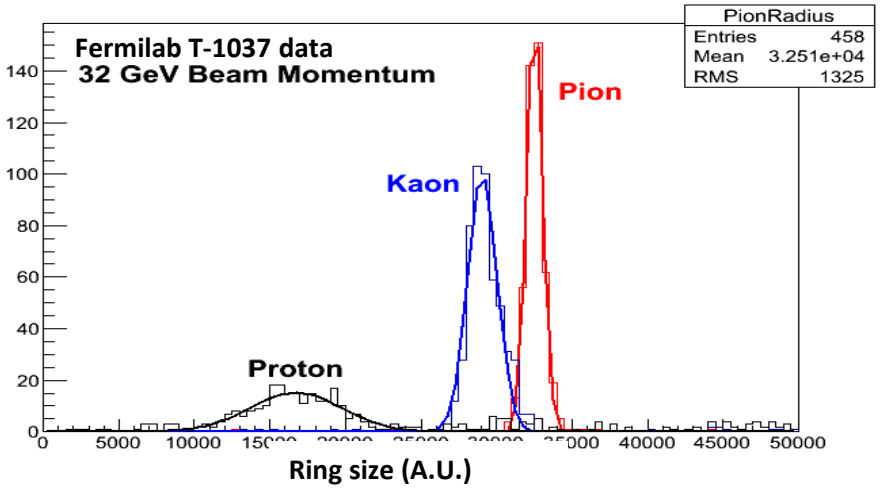
(b) Fused silica radiator for barrel DIRC detector. Data are measured by the BaBar DIRC [25]

Gas RICH
- The Design

- Hadron ID for p>10GeV/c require gas Cherenkov
  - CF_4 gas used, similar to LHC_b RICH
- Beautiful optics using spherical mirrors
- Photon detection using CsI–coated GEM in hadron blind mode
  - thin and magnetic field resistant
- Success beam tests

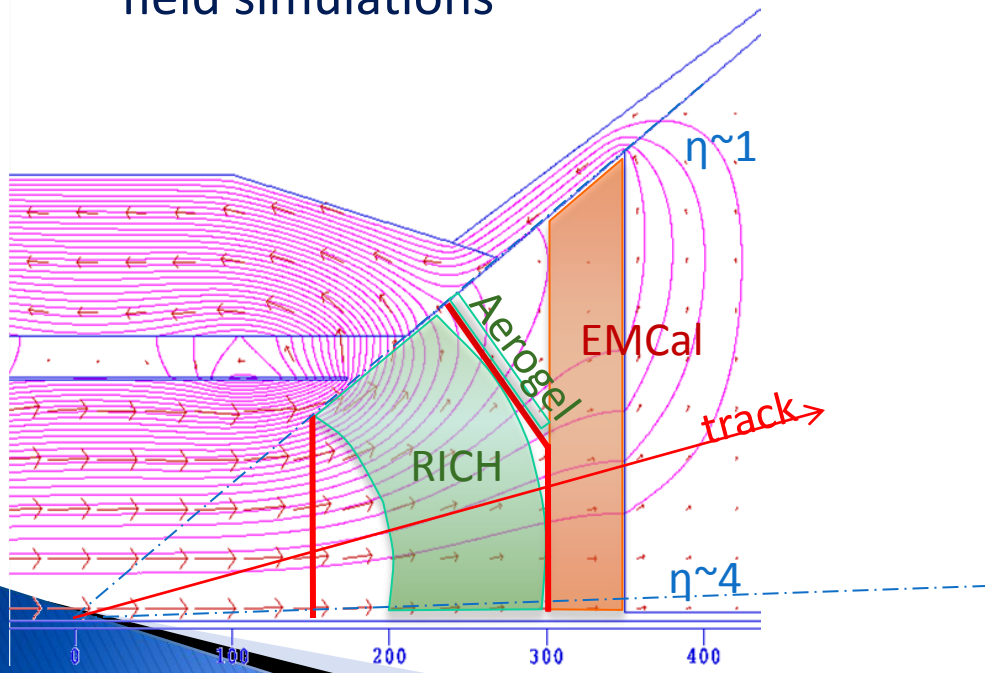


Courtesy : EIC RD6 TRACKING & PID CONSORTIUM



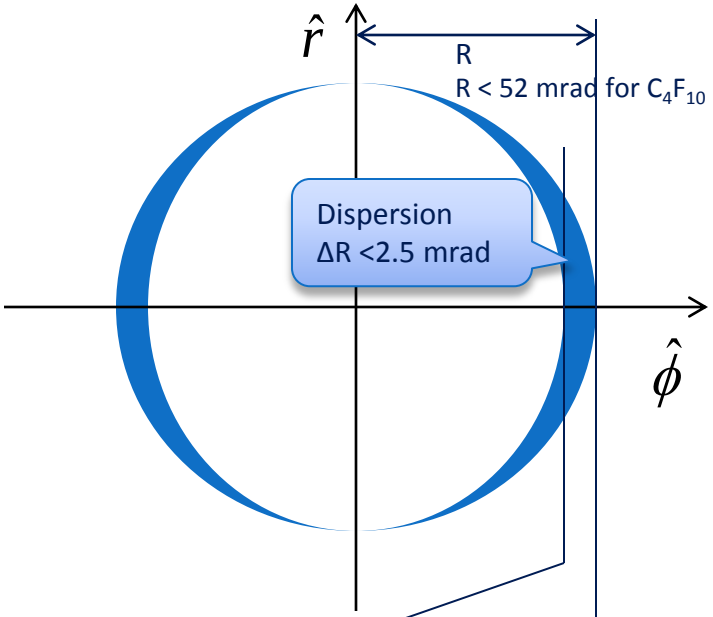
Field effect - distortion for RICH

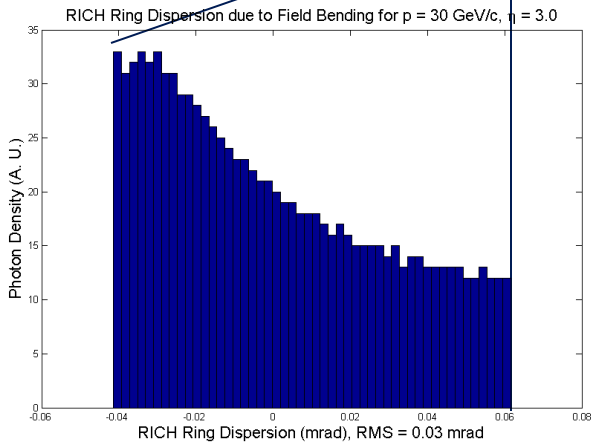
- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume with the yoke
- We can estimate the effect through field simulations



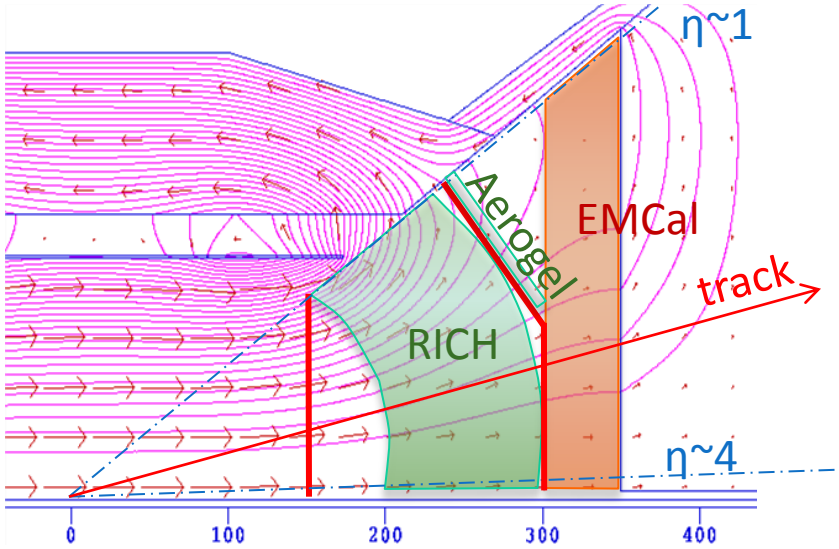
A RICH Ring:

Photon distribution due to tracking bending only



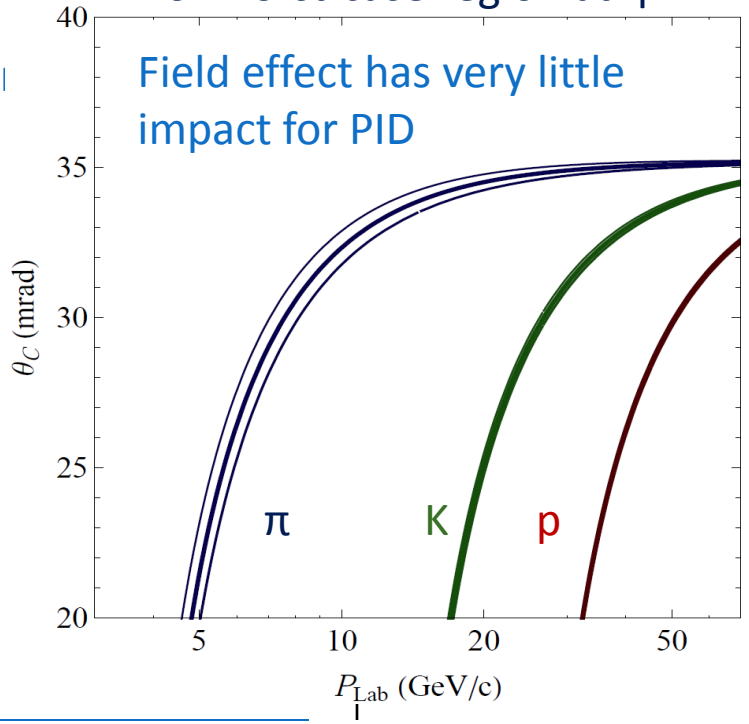


Gas RICH - performance

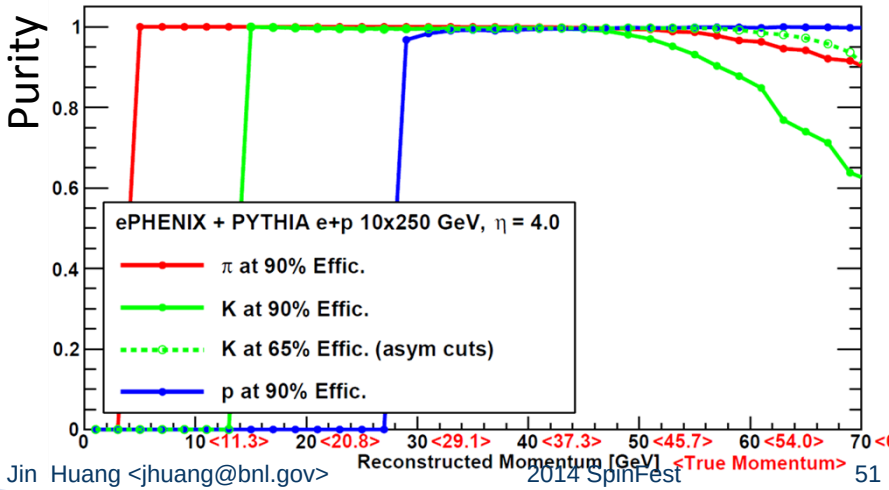


- Strong fringe field unavoidable
  Tuned yoke → magnetic field line most along track within the RICH volume
  → very minor ring smearing due to track bending
- Reached good hadron ID to high energy

Ring radius ± 1σ field effect for worst-case region at η~+1



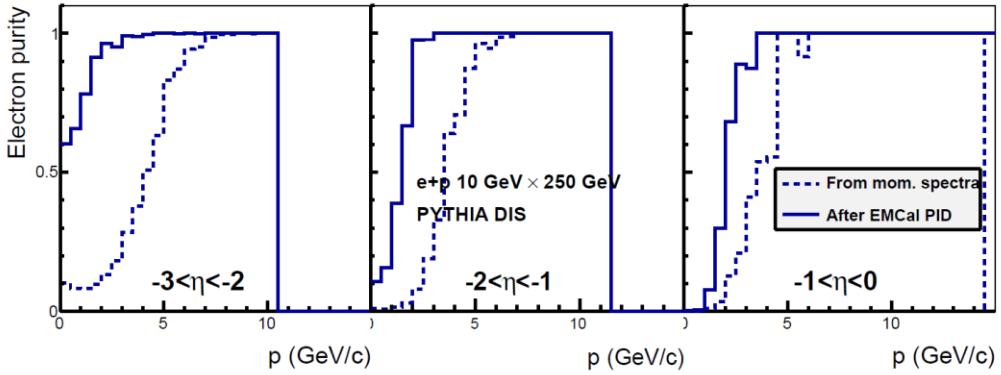
PID purity at η=4 (most challenging region w/ δp)



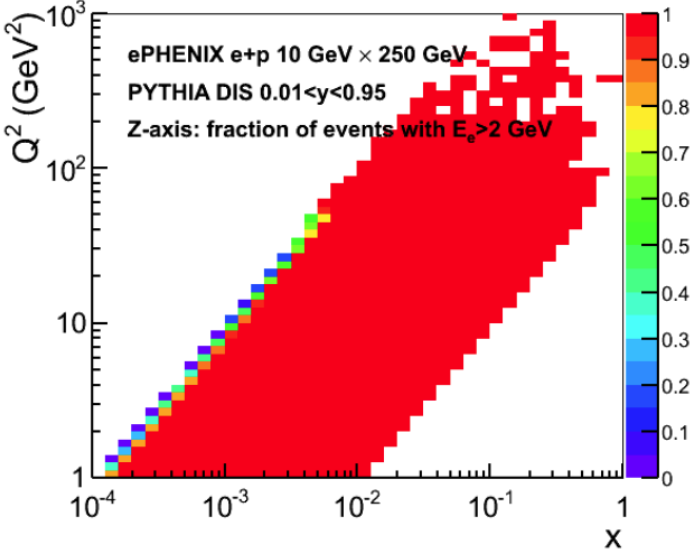
Calorimeters

- EM Calorimeter
  - Measure electrons and photons
  - e-going: crystal calorimeters, dE/E~1.5%/√E
  - Barrel and h-going: W- and Pb-scint. sampling calorimeter, dE/E~12%/√E
  - GEANT simulation show electron background of photon conversion is negligible
- Hadron Calorimeter
  - Cover -1<η<+5, great for ID diffractive events
  - Also serve as magnetic field return

Electron purity after EMCal PID



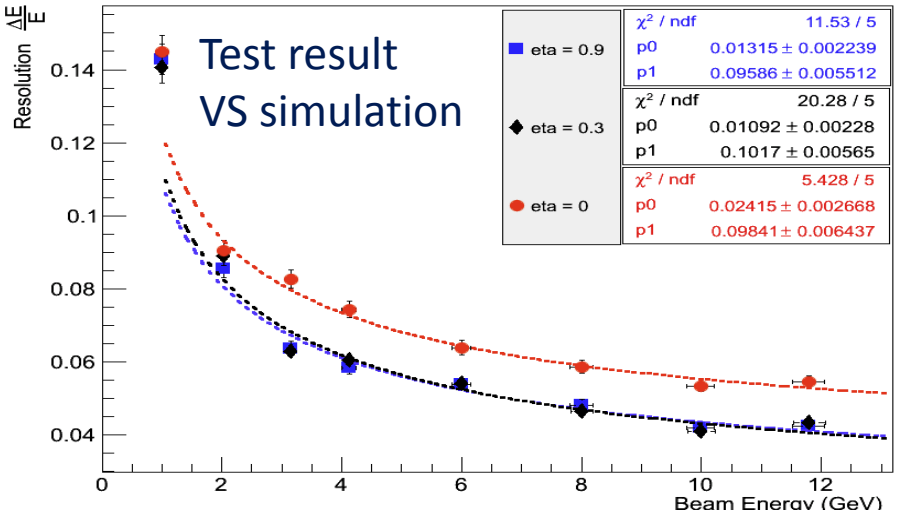
Fraction of DIS event with good electron ID



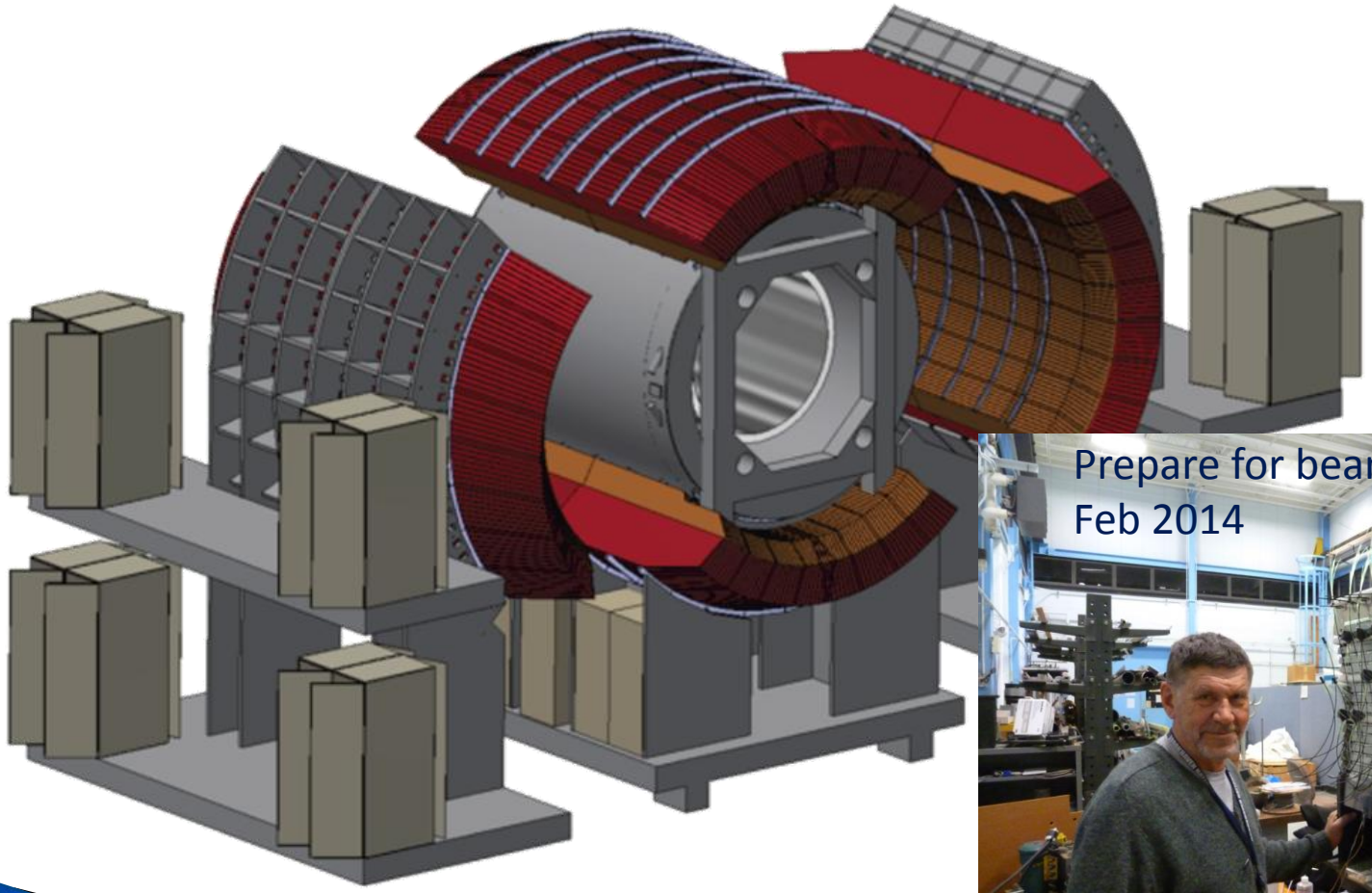
EM Calorimeter prototypes

Courtesy: A.Kiselev (BNL) DIS2014
O. Tsai (UCLA) CALO2014

- Density - 10.17 g/cm3,
- X0 ~ 7 mm, Rm ~ 2.3 cm,
- Sc. Fibers -SCSF78 Ø 0.47 mm
- Spacing 1 mm center-to-center
- Sf -2% (electrons),
- Resolution ~12%/√E
- Tapered module → Azimuthal projective
- Solid object for ease of mechanical support



Hadron calorimeters – sPHENIX concept and beam tests

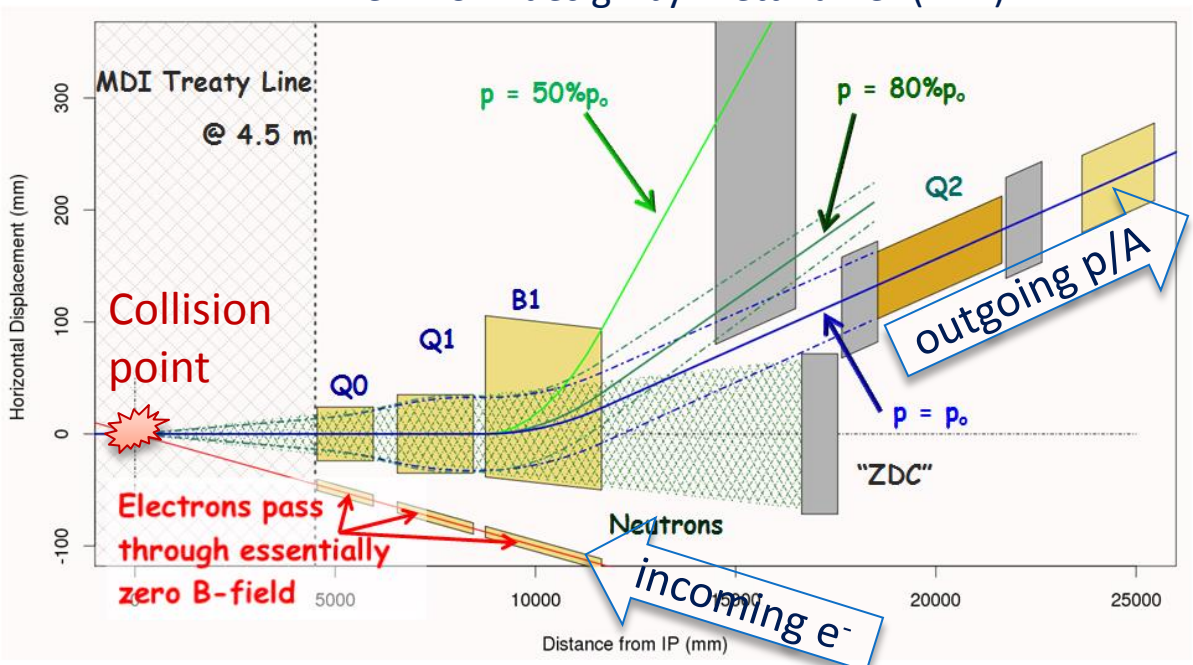


Integration of detector to eRHIC

Courtesy: E.C. Aschenauer (BNL), A.Kiselev (BNL), DIS2014

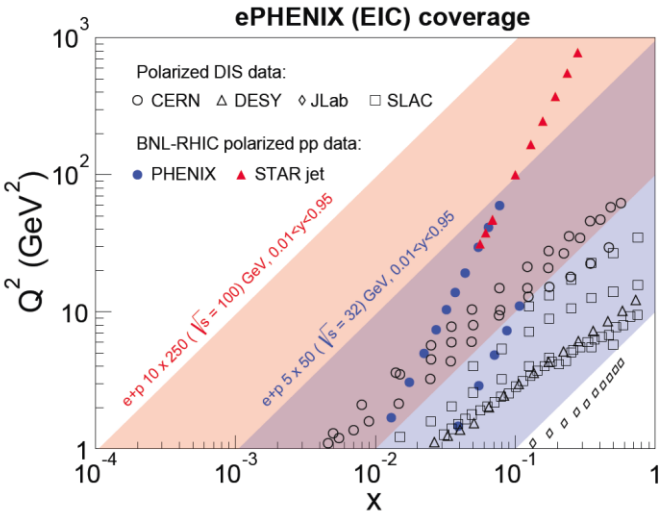
- For |z|<4.5m, machine-element free region for detectors
- For shared region: close collaboration between BNL EIC taskforce and Collider-Accelerator Department with on-going studies:
  - Roman Pots
  - Zero Degree Calorimeter
  - Low Q2 tagger
  - Luminosity detector
  - Electron polarimeter
  - IP12: Hadron beam polarimeter

An eRHIC IR design by Brett Parker (BNL)

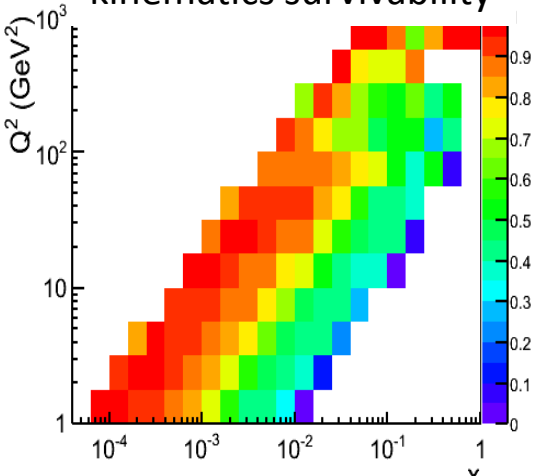


Physics performance: longitudinal spin structure of proton

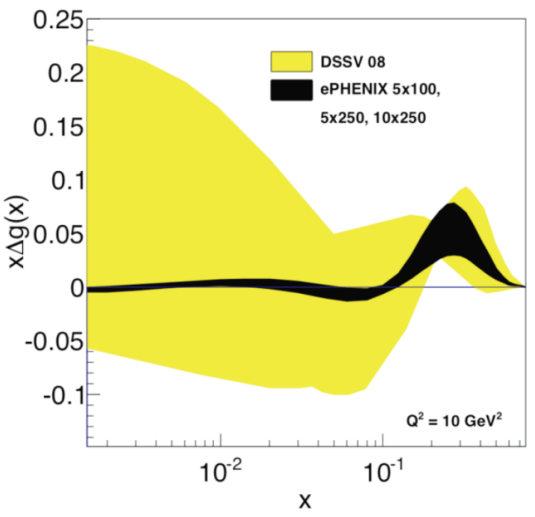
- ePHENIX will significant expand the x-Q^2 reach for longitudinal spin measurement
- EM calorimeter and tracking deliver good kinematic determination and particle ID
- Precise evaluation of gluon and sea quark spin



ePHENIX electron kinematics survivability



ePHENIX gluon helicity projection

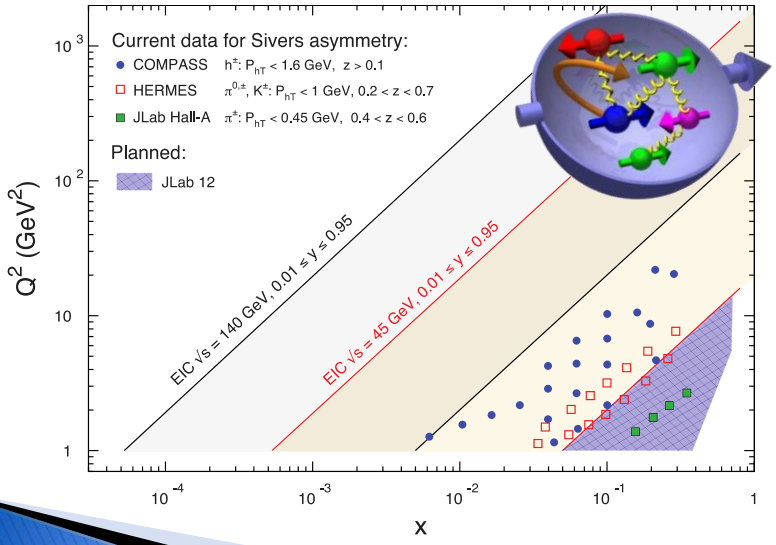


High x and Q2 region will be better determined using info from hadron final states

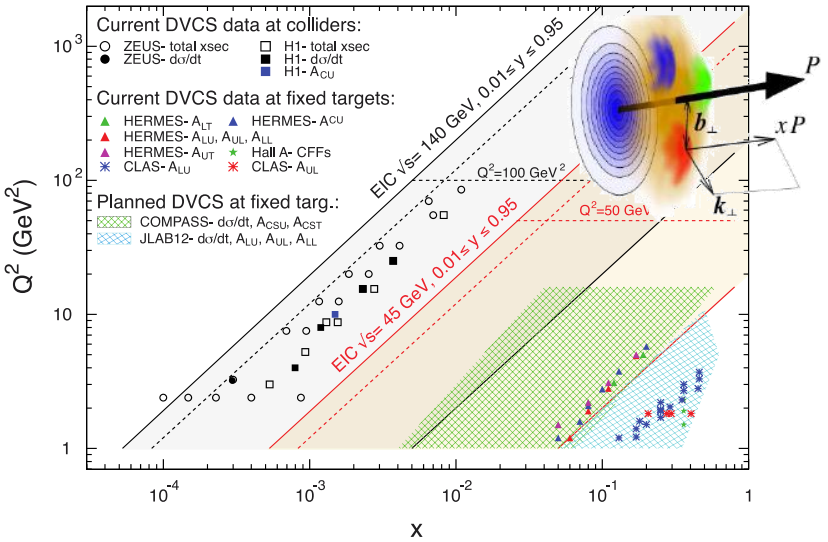
Physics performance: Transverse structure of nucleon

- Deliver clean measurement for SIDIS and DVCS
- Significantly expand x-Q^2 reach and precision for such measurements
- Extract sea quark and gluon's transverse motion and their tomographic imaging inside polarized nucleons
- Sensitive to the orbital motion of quark inside proton

SIDIS Sivers Asymmetries



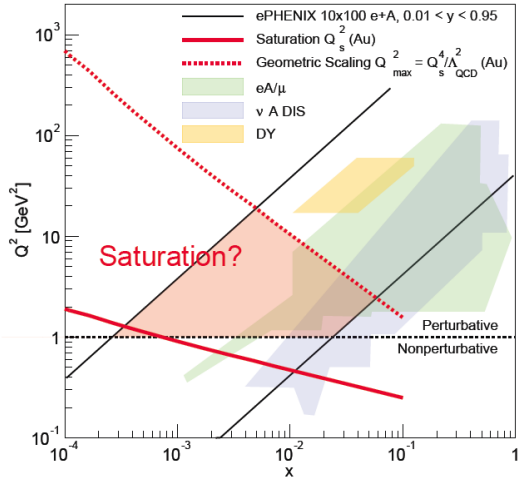
DVCS



Physics performance: Probing gluon saturation

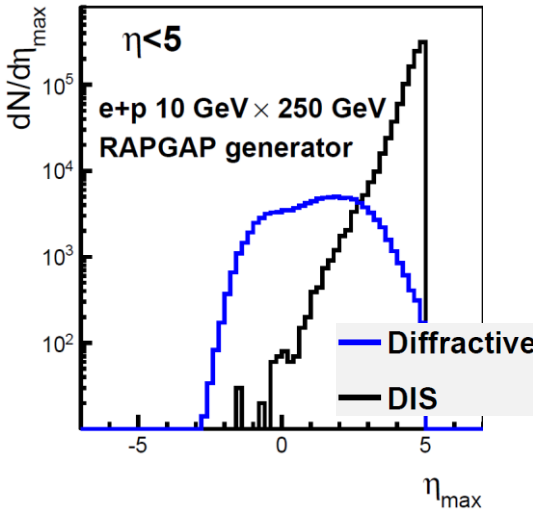
- ePHENIX is at the kinematic range to inspect the transition to gluon saturation region and their nuclear size dependent
- Large H-cal coverage (-1<η<+5) provide clean ID of diffractive events with reasonable efficiency through the rapidity gap method
- Delivering high precision diffractive-to-total cross section ratio measurement, which is very sensitive to the gluon saturation

Probing saturation region in electron kinematics

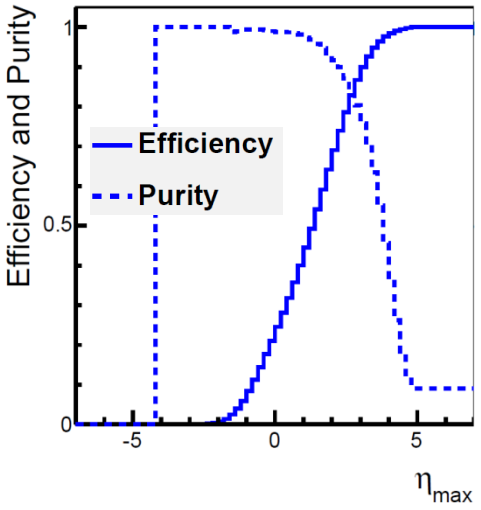


ID diffractive events using ePHENIX calorimeters

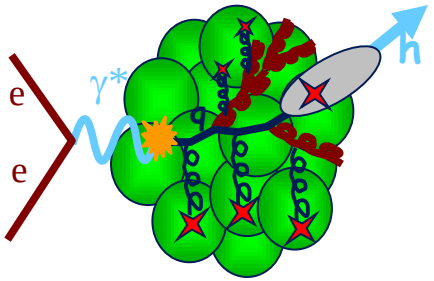
η of most forward going particle



Eff./Purity with η_{MAX} cut

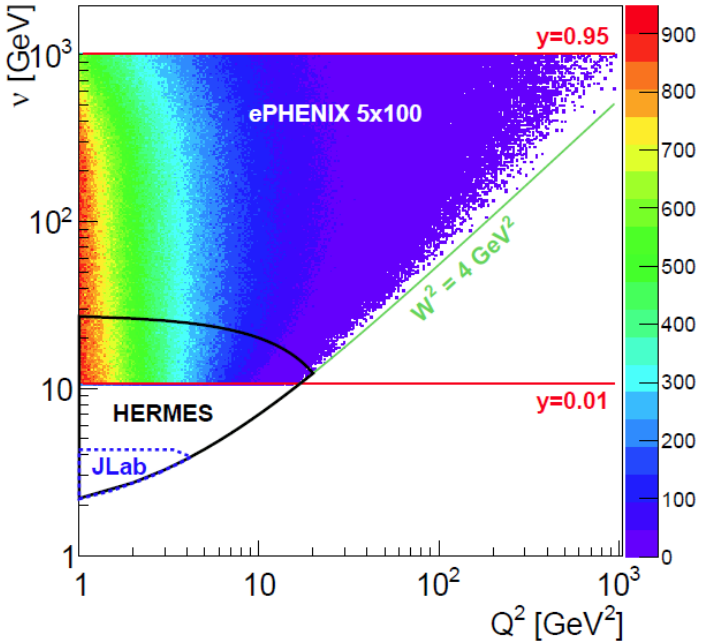


Physics performance:
parton propagation through nuclear matter

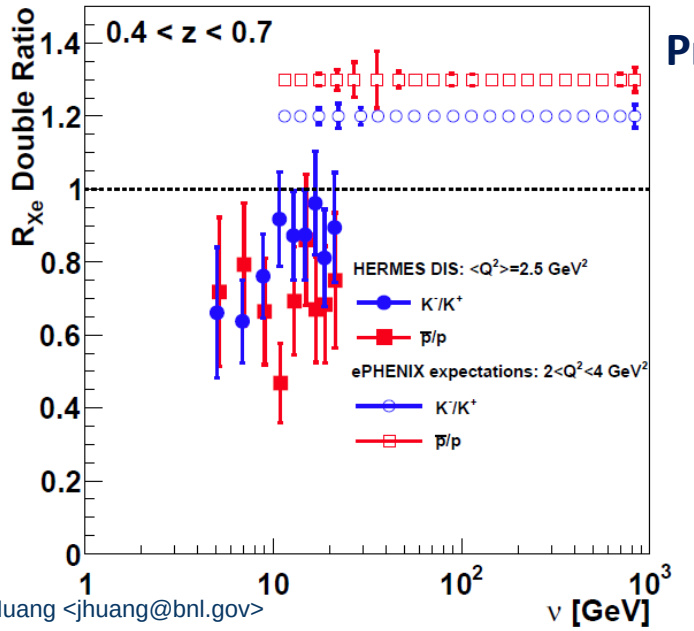


- SIDIS in e-A collisions probe color neutralization and harmonization as it propagate through nuclear matters
- ePHENIX provide a set of flexible handles : struck quark's energy and flavor, virtuality of DIS, geometry of the collision, specie of nuclei.
- Also possible for D-meson production through kinematical reconstruction of identified decay products

Energy transfer ν VS Q2 **coverage**



ePHENIX projection for nuclear modification ratio



Precision

Physics before the EIC era:

See lectures of Ming Liu and John Lajoie

- The ePHENIX forward detector can be constructed earlier → a unique forward program with RHIC's pp/pA collision
- The collaboration is drafting a white paper to discuss the physics program

ePHENIX GEM + H-Cal

→ Forward jet with charge sign tagging

→ Unlock secrets of large A_N in hadron collisions

+ reuse current silicon tracker & Muon ID detector

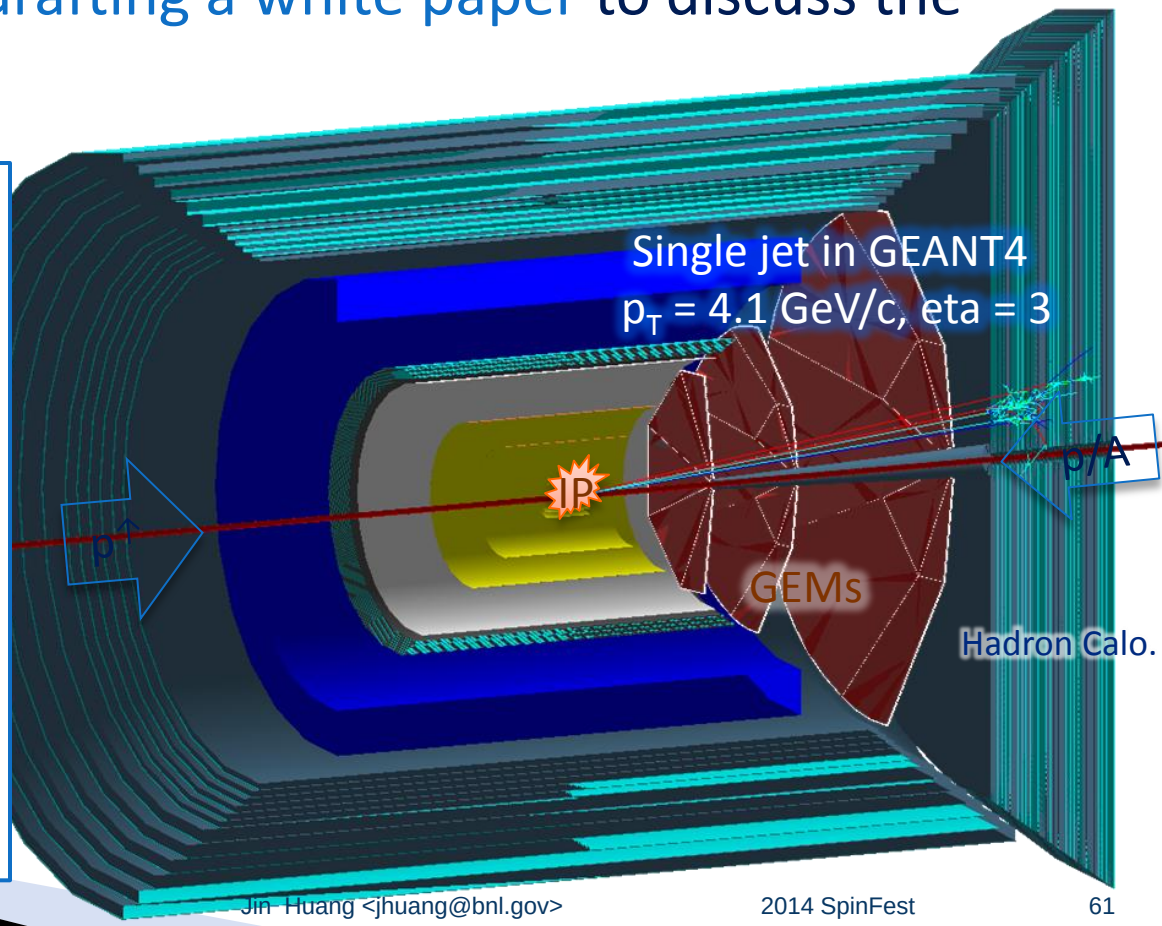
→ polarized Drell-Yan with muons

→ Critical test of TMD framework

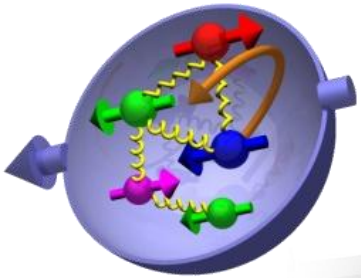
+ central detector (sPHENIX)

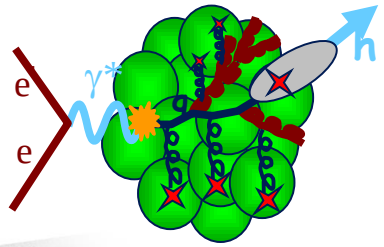
→ Forward-central correlations

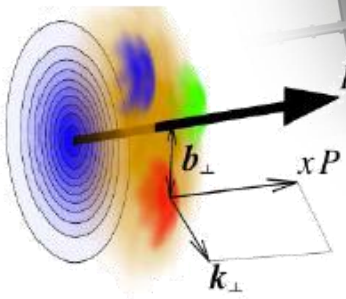
→ Study cold nuclear matter in pA

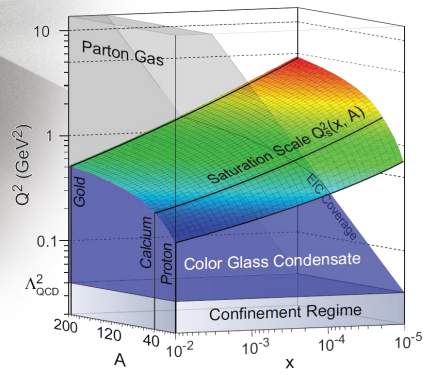


Summary







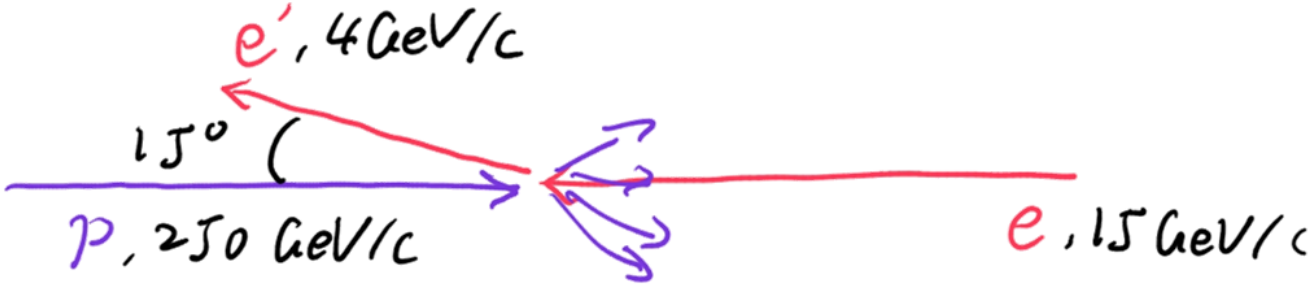


- EIC: precision study of gluon in proton and nucleis
- An upgrade path that harvests **pp, pA and AA** physics and leads to an EIC era
- 2025+ EIC detector: A comprehensive day-one eRHIC detector for studying nucleon structure and dense nuclear matter

Home work

Home work

- eRHIC baseline design consists of 15 GeV/c polarized electron beam collide with 250 GeV/c polarized proton beam.
  a) What is the center of mass energy of the collision system?
  b) If one want to reach the same center of mass energy in a fix-target experiment (proton at p=0 in lab frame), what will be the electron beam energy?
  c) What is the highest energy electron beam human race ever accelerated? How about muon beam?
  d) In eRHIC, a DIS electron is detected with p_Lab = 4GeV and polar angle of 15 degree, what is the x and Q^2 for this event



  e) For the same DIS electron (same √s, x and Q^2), what will be its polar angle and momentum, if it is a fix target experiment
  f) What is the advantage of using a collider in high energy scattering?